WHAT IS MUSICAL CREATIVITY? INTERDISCIPLINARY DIALOGUES AND APPROACHES

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WHAT IS MUSICAL CREATIVITY? INTERDISCIPLINARY DIALOGUES AND APPROACHES

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Editorial: What Is Musical Creativity? Interdisciplinary Dialogues and Approaches

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Editorial on the Research Topic

What Is Musical Creativity? Interdisciplinary Dialogues and Approaches

INTRODUCTION

Creativity is central to human life, and the domain of music is no exception (Boden, 2004; Cook, 2018). From learning to play an instrument to performing, composing, and improvising, much of our music-making activities are deeply associated with creative thought and action (van der Schyff et al., 2018). Given its complex phenomenology and variety of manifestations, understanding musical creativity remains a crucial, yet difficult goal of current scholarship on the musical mind. How exactly can musical creativity be defined? What are its main characteristics, and how do these play out across different musical settings? On what neural, social, cognitive, and behavioral resources it is based? We are convinced that clarifying what musical creativity entails requires a dialogue between theoretical analysis, experimental research, and the practical teaching of everyday music-making. To do so, we have deliberately invited submissions from colleagues working in diverse areas, promoting a cross-pollination of ideas and insights. Hence, this edited collection includes articles exploring how creativity plays out in concrete musical contexts from a range of perspectives: here the views of composers, music theorists, musicologists, neuroscientists, ethnomusicologists, educators, and psychologists, take the form of conceptual analyses, literature reviews, and original empirical studies, ensuring a complementarity of epistemological approaches and methods. Such a variety of contributions fosters fascinating opportunities to examine from new angles the mechanisms associated with creative practice and experience, as well as their interplay with broader aspects of human cognition. This allows us to explore, in novel ways, the neural, psychological, and behavioral processes involved in (the development of) musical creativity; to gain a deeper understanding of the social and individual dimensions of creative music-making; to put novel ideas and hypotheses to the test; and to offer syntheses of methodologies and findings pertaining to diverse research domains. While it is neither possible nor necessary to reduce the findings of the contributions in this Research Topic to a discrete number of outcomes, nevertheless the approaches taken can be grouped into the following three categories: (i) reviews and theoretical investigations, where existing assumptions and conceptual frameworks are systematically re-examined on the basis of novel insights, (ii) contextual framings, in which musical creativity is addressed within specific domains of interest (e.g., music performance), and (iii) implementations in composition and musical analysis, where novel theoretical and practical tools are proposed to illuminate how creative thought develops across a web of compositional processes. In what follows, we describe how the content of each contribution speaks to one of these categories, and

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we offer general insights intended to stimulate further discussion across diverse areas of enquiry and practice.

REVIEWS AND THEORETICAL INVESTIGATIONS

Contributions pertaining to the category "reviews and theoretical investigations" offer innovative approaches to reconceptualizing existing findings and systematically reexamining previous theoretical assumptions. An excellent example of such recontextualization can be found in the article by Barrett et al., which challenges past biases in the scientific literature privileging individualist conceptualizations of creative production over more collaborative conceptualizations. Conducting a systematic review of recent literature on collaborative musical creativity, the authors examined factors such as the research setting (educational or professional), the style of music featured (jazz being the most common), the main questions asked and reasons for asking them (focusing on learning vs. on the artistic product), and how social factors and musical factors were seen to interact. Among other things, the researchers report that the vast majority of the contributions considered were found to rely on qualitative methods, and that all but one had addressed only Western styles of music. Future studies seeking to correct these imbalances might therefore aim to offer more diversity regarding methodological approach and cultural setting. By providing greater conceptual clarity and broader views, allowing findings to be compared and generalized, such future studies might in turn inspire novel approaches to examining and challenging pre-existing theoretical assumptions and biases, of which we may be largely unaware.

The fascinating article by Schubert goes in this direction when it asks us to rethink existing definitions of creativity, proposing instead a new framework based on a *spreading activation model*. On this view, creative (e.g., musical) ideas might be best understood as highly connected nodes which "encode, store, process, and recall simple pieces of information." By exploring the principles governing the network in which such nodes operate, the role of positive affect for creative activity is given major emphasis.

A complementary analysis on the interactive and action-based components of musical creativity is offered by Schiavio and Benedek. Drawing on the conceptual resources of enactive cognitive science (see Varela et al., 1991), they examine creative cognition as an adaptive phenomenon that "originates in a primordial, and necessary, sense-making activity—a bio-cognitive inclination to create, transform, and maintain viable relationships with the world." The move, it is suggested, can help mitigate two of the most important dichotomies of the field—that between individuality and collectivity and that between domain-generality and domain-specificity.

Exploring the biological and adaptive roots of creative cognition is also the main goal of the article by Podlipniak, which examines human musical creativity from the perspective of gene-culture coevolution. According to this perspective, creative behaviors have downstream effects upon gene flow, and gene flow in turn feeds back to influence those behaviors. Two opposing forces are proposed as central to such gene-behavior interaction: plasticity and canalization. Behaviors must be sufficiently plastic to be differently acted upon by natural and sexual selection. However, too much variance can be invisible to selection, and hence only behaviors that remain consistent over time, becoming canalized, sufficiently influence genetic transmission. The inexhaustible creative potential of the human musical system is proposed to arise not solely from plastic forces, but from the interaction of such forces with canalized structures such as the hierarchies of pitch and rhythm found across virtually all human cultures.

An approach to musical creativity based on statistical learning is developed by Daikoku et al.. Having reviewed important research on the neural and computational roots of statistical creativity, they propose a hierarchical model that brings together *shallow* and *deep* statistical learning (see e.g., LeCun et al., 2015), suggesting that musical creativity involves the integration of shareable units of information and the temporal dynamics of uncertainty. As we will see next, a similar focus on brain dynamics remains a core aspect of research on musical creativity, particularly when it seeks to address concrete questions contextually.

CONTEXTUAL FRAMINGS

Musical creativity is expressed through a variety of manifestations, processes, and outcomes spanning a range of situated contexts and dimensions. The contributions that fall under the category "contextual framings" offer an in-depth look into one or more of these dimensions. The article by Farrugia et al., for example, reports on a single-subject, EEG study based on an ecological paradigm of live musical improvisation. In the experiment, electroencephalography was combined with retrospective ratings to allow a "mental replay" of the variety of subjective states involved in the performance, with a particular focus on the temporal dimension (i.e., the internal time felt by the improviser) characterizing the creative activity.

The musical brain is also at the heart of the contribution by Colombo et al.. Here, two groups of participants were asked to rate the creativity of a musical piece they had just listened to. The first group received transcranial direct current stimulation (tDCS) to inhibit the activation of the auditory Mirror Neuron mechanism (see e.g., Keysers et al., 2003), while the second group served as a control (receiving only sham stimulation). Results showed that, among other things, participants in the first group rated the stimulus as less creative than the second group did, suggesting that the evaluation of specific aspects of musical creativity (i.e., innovation and excitement) partially relies on mirror-like activity.

The context of human-computer co-creation represents another area where various aspects of musical creativity may be explored, variously implemented, and put to a test. In this regard, the paper by Zacharakis et al. introduces a computational melodic harmonization assistant (CHAMALEON), and investigates how expert and novice composers make use of it during a melodic harmonization task. Results indicate that novices found the system more useful than experts, and that interaction with CHAMALEON gave rise to more explorative strategies when compared to harmonizations realized without its support.

In a way complementary to the studies previously described, Alkaei and Küssner take a qualitative approach to investigating creativity in the improvisatory tradition of Arabic *taqsim*. The authors interviewed three Berlin-based, professional oud players of Syrian origin about such aspects of the creative process as the difference between improvisation and composition, and how migrating to Europe has influenced their approach to improvisation. This approach appears well-suited to help reveal the richness of subjective creative experience from a transcultural perspective, helping to build a new picture of how *taqsim* is understood and performed in relation to an artist's individual agency and culture.

This goal of evaluating and expanding our theoretical assumptions about what creativity is, and how it works, is elegantly pursued by Huovinen. Here the author notes that individual researchers rarely offer explicit arguments for choosing one theory over another, typically proceeding "as if they would have already made up their minds." Huovinen's solution to the problem is novel: while specialists in the field of creativity may have too much prior experience to offer unbiased comparisons of different theories, students are actually quite capable of "relat[ing] to more complex, scholarly theories," serving as a valuable step toward assessing theories rather than simply assuming them to be correct *a priori*. Asking a cohort of music students to rate different theories of creativity for their applicability to four types of target activity—composition, improvisation, performance, and ideation— Huovinen finds that students' evaluations and argumentative strategies differed for each realm of activity, as well as differing as a function of the student's musical background.

IMPLEMENTATIONS IN COMPOSITION AND MUSICAL ANALYSIS

While, in principle, scientific studies of musical creativity ought naturally to be of interest not only to other scientists but also to the sorts of creative musicians whose behavioral processes are being studied, the conceptual gap between these two realms is not always intuitively easy to bridge. In that light, two contributions in the present Research Topic are likely to be of particular interest for the focus they place on elucidating high-level compositional processes.

The paper by Besada et al. focuses on a single work, Iannis Xenakis's *Psappha*, addressing a specific compositional procedure that is idiosyncratic not only to that composer, but to that specific work. Taking the perspective that a continued belief in "the romantic myth of the lone genius" —portraying a composer's thought processes as *different in kind* from those of "normal" human beings—makes "musical creativity unnecessarily hard to study," the authors present a reconstruction and analysis of Xenakis's thought processes in the composition of *Psappha* by way of a general model of "normal" or "everyday" creativity, the *blending theory* of Fauconnier and Turner (2002). By focusing specifically on the sense of time in this work—using notions that are general to cognition, not specific to music—the authors not only shed new light on the structure of the work and this specific composer's unique and idiosyncratic creative process, but also pioneer new avenues for exploring how musical meanings can be formed and transformed in the compositional process.

With a similar focus on music composition and analysis, the contribution by Spence introduces a model (named *Experimental Composition Improvisation Continua* or ECIC) thought to capture the range of continuities between composition and improvisation often displayed by experimental music. It is argued that its application might help researchers and analysts to trace, isolate, and compare those indeterminate musical properties that might be attributed to the environment in which the performance takes place, improvisational style, as well as the performer's action or inaction.

In conclusion, the present Research Topic addresses a number of crucial issues in creativity studies by focusing on the domain of music. Here, theoretical, empirical, and practice-based insights are developed, examined, and implemented across different settings, presenting novel findings, and conceptual tools that can be relevant to composers, musicians, and researchers from across diverse fields. While even a sizeable collection such as ours can offer only a partial view upon so complex a topic as musical creativity, our intention, as stated in our title, has been to inspire *dialogue*, and promote novel *approaches* to bringing artists and researchers together across fields, disciplines, cultures, and orientations. In a sense, this represents a valuable way forward *per se*, as many researchers in the field will be able to benefit from the rich interdisciplinary resources developed in the present collection, delve into its multiple theoretical, empirical, and practical dimensions, and access insights and conceptual tools from scholarly territories that may often appear too distant from theirs. It should also be noted that such interdisciplinary dialogues permeate music itself, involving performers, composers, listeners, educators, and scholars. Similarly, the study of creativity has a rich and sprawling history, boasting a vast diversity of approaches—which have considerably expanded understanding, challenged assumptions, and inspired new questions. While there undoubtedly remains much to learn about this fascinatingly alluring faculty, we hope to have inspired new dialogues about, and approaches to, the study of musical creativity.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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REFERENCES

Boden, M. A. (2004). *The Creative Mind: Myths and Mechanisms*. London and New York: Psychology Press.

Cook, N. (2018). *Music as Creative Practice*. New York: Oxford University Press.

Fauconnier, G., and Turner, M. (2002). *The Way We Think: Conceptual Blending and the Mind's Hidden Complexities*. New York: Basic Books.

Keysers, C., Kohler, E., Umiltà, M. A., Nanetti, L., Fogassi, L., and Gallese, V. (2003). Audiovisual mirror neurons and action recognition. *Exp. Brain Res.* 153, 628–636. doi: 10.1007/s00221-003-1603-5

LeCun, Y., Bengio, Y., and Hinton, G. E. (2015). Deep learning. *Nature* 521, 436–444. doi: 10.1038/nature14539

van der Schyff, D., Schiavio, A., Walton, A., Velardo, V., and Chemero, A. (2018). Musical creativity and the embodied mind: exploring the possibilities of 4E cognition and dynamical systems theory. *Music Sci.* 1, 1–18. doi: 10.1177/2059204318792319

Varela, F., Thompson, E., and Rosch, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press.

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Dimensions of Musical Creativity

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Current literature on creative cognition has developed rich conceptual landscapes dedicated to the analysis of both individual and collective forms of creativity. This work has favored the emergence of unifying theories on domain-general creative abilities in which the main experiential, behavioral, computational, and neural aspects involved in everyday creativity are examined and discussed. But while such accounts have gained important analytical leverage for describing the overall conditions and mechanisms through which creativity emerges and operates, they necessarily leave contextual forms of creativity less explored. Among the latter, musical practices have recently drawn the attention of scholars interested in its creative properties as well as in the creative potential of those who engage with them. In the present article, we compare previously posed theories of creativity in musical and non-musical domains to lay the basis of a conceptual framework that mitigates the tension between (i) individual and collective and (ii) domain-general and domain-specific perspectives on creativity. In doing so, we draw from a range of scholarship in music and enactive cognitive science, and propose that creative cognition may be best understood as a process of skillful organism–environment adaptation that one cultivates endlessly. With its focus on embodiment, plurality, and adaptiveness, our account points to a structured unity between living systems and their world, disclosing a variety of novel analytical resources for research and theory across different dimensions of (musical) creativity.

Keywords: musical creativity, creative cognition, music performance, music composition, enactive cognition

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The proliferation of novel enquiries, theories, and methodologies emerging within a research domain, often gives rise to a multiplicity of sub-areas exhibiting narrower focus and increased specialization. Explorations within specialized fields can facilitate insights on very specific aspects of a problem, which sometimes only apply in this very context, and sometimes bear relevance to overarching issues. Hence, the process of fragmentation poses the fascinating challenge of whether findings observed in resulting sub-fields generalize across them, and how they could be fruitfully integrated to expand their explanatory reach. By bringing together insights from complementary as well as contrasting schools of thought, such integrative accounts usually appear well-positioned to offer richer understandings of the range of phenomena under examination. In the natural sciences, for example, the synthesis of diverse theories into generally accepted canons has been often associated with increased knowledge and scientific improvement. Balietti et al. (2015) illustrate this point by referring to Newton's blending of "celestial and terrestrial forces" and to how "Maxwell unified electricity and magnetism in one single force called electromagnetism."

Notably, the tendency to build on narrower lines of enquiry to develop broader frameworks is not limited to the natural sciences; it also arises in much research on human cognition and its various manifestations. Here, a number of key concepts, such as "experience," "thought," or "consciousness," have been traditionally addressed from a variety of angles, leading to approaches that employ different analytical instruments ranging from the examination of one's neural activity to the classification of verbal reports and descriptions. As such, a number of objects of investigation in this area remain blurred and ill-understood; and unlike phenomena with more specific, measurable features, the properties associated with mind and subjectivity do not easily fit within one domain, purportedly leaking into other scholarly territories. Perhaps the potential ambiguity of outcomes that this process brings forth is a price well worth paying for promoting dialogue and epistemological diversity. And in any case, whether the process of systematization will give rise to a unified "grand" theory or not, heterogeneity of ideas can be generally considered as a sign of good health for scientific enterprise.

In this regard, the study of creativity is no exception. In fact, the latter can be seen as emblematic for the potential conflicts that arise when considerations from a wide spectrum of research trajectories are combined into novel constructs, methods, and theoretical models. Indeed, while plurality of approaches is a valuable aspect of scientific discovery and its conventions of significance (see e.g., Benedek and Jauk, 2014), "we should also consider how each one of them constructs the meaning of creativity and guides its practice" (Glăveanu, 2014, p. 6). Within the rich variety of voices populating the creativity discourse, we highlight two distinctions that are particularly prominent and that have fragmented, if not polarized the field. The first one involves the notions of *individual* and *collective* creativities. As we will see, this differentiation refers to two perspectives that conceive of creativity as a property of the lone agent and as a multiply realized, social phenomenon, respectively. The second important distinction involves viewing creativity from a *domain-general* or *domain-specific* perspective. Both distinctions, we suggest, highlight specific fragmentations in the field, as scholars usually tend to adhere to either approach and pursue it predominantly in their research.

In the present article, we take a closer look at both distinctions. We present individual *vs*. collective as well as domain-general *vs*. domain-specific accounts of creativity, and review relevant contributions that adhere to such perspectives. Because our aim is to mitigate tensions between said approaches, in turn laying down the basis of a framework that looks at creativity in more synergetic terms, we subsequently explore scholarly domains in which these dichotomies appear being less rigid. We begin with examples, arguments, and intuitions from the areas of music performance and music composition. Our analysis emphasizes how individual and collective forms of creativity may not be understood as alternatives: recent music scholarship trades the focus on single agents and groups to their underlying relational principles and embodied entanglements, helping us re-organize the conceptual topography of creative phenomena (see Reybrouck, 2006; Nagy, 2017; Cook, 2018; van der Schyff et al., 2018). We then introduce the main tenets of *enactive cognitive science*—a school of thought that conceives of the mind as situated action-as-perception (Varela et al., 1991; Di Paolo et al., 2017; Gallagher, 2017). We observe how, on this account, two main properties of creativity (*novelty* and *functionality*) can also be seen to play an enabling role in shaping mental life more generally, describing the capacity of biological systems to establish, transform, and re-organize meaningful adaptive relationships with their niche. This helps us trace a continuum between general bio-cognitive principles and creative thought and action, thereby reframing the issue of domain-general vs. domain-specific creativity into more conciliatory terms. In doing so, we offer an understanding of creativity as a process of skillful organism–world adaptation. This interpretation allows us to move beyond the study of explicit thinking abilities that characterizes much creativity research to include more situated, dynamic, and world-involving aspects of cognitive life and subjectivity, which may not be captured when postulating initial distinctions. Finally, we proceed to illustrate how this conceptual framework may lead to precise empirical questions by outlining a possible experimental paradigm. **Figure 1** depicts the main structure of the paper and its main points.

Before we begin, it should be noted that several authors who work in embodied and enactive cognitive science, as well as ecological dynamics and distributed cognition, have written on creative processes (see e.g., Hristovski et al., 2011; Vallee-Tourangeau and Vallee-Tourangeau, 2014; Vallee-Tourangeau et al., 2016; Kimmel et al., 2018; Torrance and Schumann, 2019). However, as Malinin (2019) argues "there is [still] minimal evidence of embodied cognition approaches in creativity research or pedagogical practices for teaching creativity skills." This paper, therefore, builds on this scholarship to provide additional grounding to such lines of research, stimulating a dialogue between different perspectives on creativity in music and beyond. To do so, we employ an interdisciplinary approach that brings together humanities, performance studies, and neuroscience in multiple ways, generating hypotheses and insights relevant to scholars belonging to each of these areas. In the next section, we start this enterprise by presenting a number of core concepts at the heart of creativity research, and we associate them with perspectives looking at creativity as a phenomenon that is either (i) individual or collective or (ii) domain-specific or domain-general.

CREATIVE COGNITION

Work on individual creativity and collective creativity, as well as research taking a domain-general or domain-specific perspective, has provided important advances to our understanding of creative thought and discovery. In this section, we offer an overview of the main tenets and findings from each of these approaches, exploring differences and lines of continuity between them. Here, we do not intend to provide a comprehensive review of the field; instead, we wish to introduce a number of key contributions that (explicitly or implicitly) tend to adhere to one or both dichotomies. This overview thus serves a double function: on the one hand, it outlines what advantages and limitations emerge when the study of creativity is framed within such given perspectives; on the other hand,

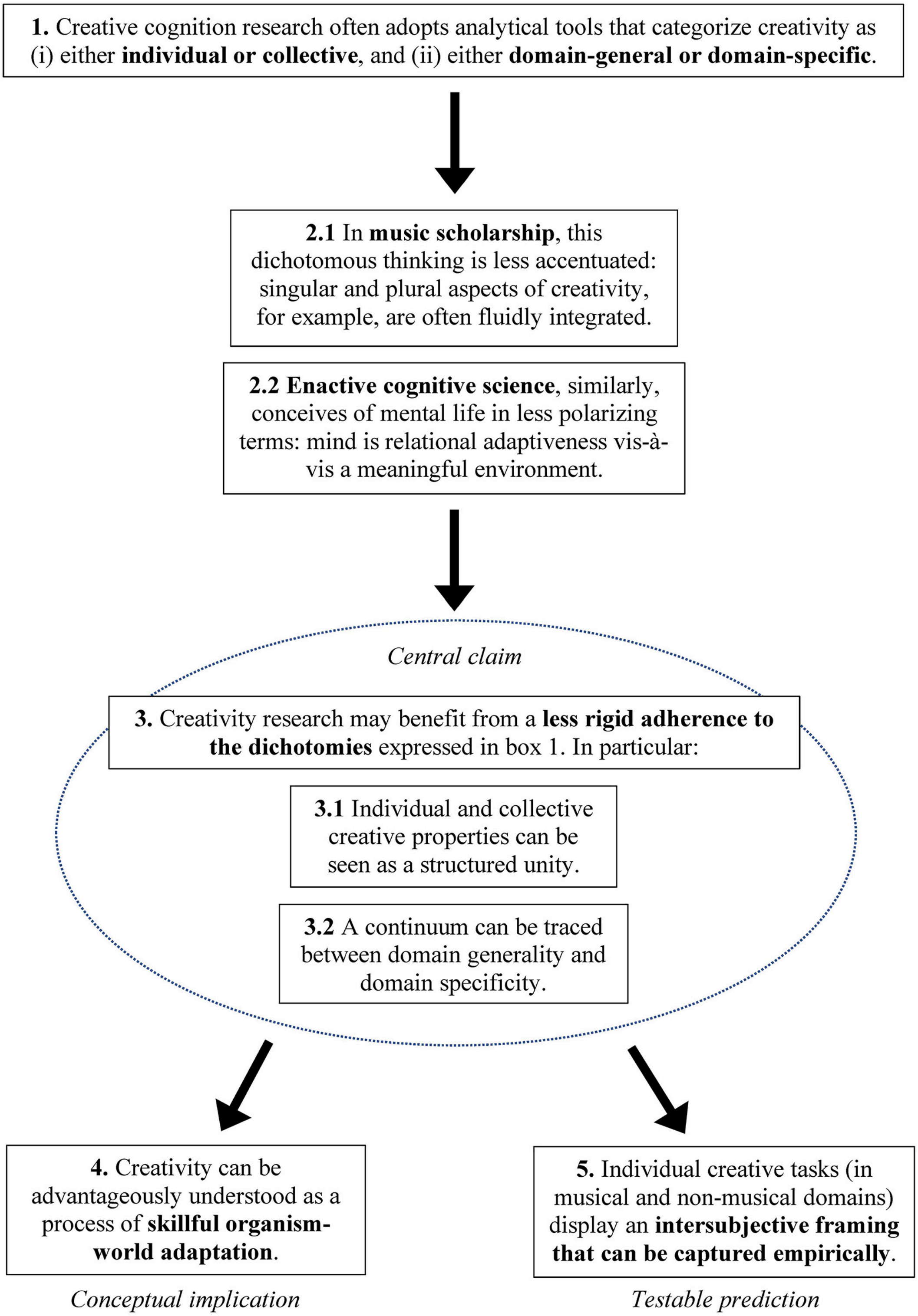

FIGURE 1 | Our contribution moves from the presentation and critical assessment of previously posed theories in creative cognition research (box 1). This is followed by a novel interpretation of recent findings from the domain of music, and by an analysis of the main tenets of enactive cognitive science (2, 2.1, 2.2). This leads us to the central claim of the paper, which is presented in box 3, and articulated in two sub-claims (3.1, 3.2). The major conceptual implication of the proposal appears in box 4, whereas box 5 introduces the main idea of a possible experimental setting, which is described in detail in the conclusive section of the paper.

it provides general insights that set the stage for later, more specific, observations.

An Individual Perspective on Creativity

Creativity research taking an individual perspective aims to understand how and why a person is creative. What happens in the mind and brain of this person when she generates a creative idea or produces a piece of creative work? What cognitive factors participate in driving creative thoughts and action? And why do some people have more creative ideas or accomplishments than others? In general, two types of creative thinking are commonly distinguished: creative idea generation and creative problem solving, also called "divergent" and "convergent" thinking creativity, with reference to Guilford's structure of intellect model (Guilford, 1967). Creative idea generation refers to the production of different possible responses to ill-defined problems. While such open-ended problems have a large solution space, ideas will differ considerably in their creative quality, with some being more novel and effective than others. In contrast, creative problem solving (or insight problem solving) refers to finding a single correct solution to a problem that cannot be solved in a straightforward, analytical way. The process of solving such problems requires to reframe the problem representation in order to overcome predominant, but inadequate solution approaches, and is often accompanied by sudden experiences of insight.

The individual perspective is particularly well suited to examine the temporal dynamics of creativity (for a review, see Lubart, 2001). Relevant stages of creative problem solving commonly include preparation (i.e., engaging with a problem), incubation (i.e., when we are no longer consciously engaged with a problem, subconscious processing typically goes on), illumination (i.e., the moment of spontaneous insight as a potential solution comes to our mind), and verification (i.e., conscious evaluation of the candidate solution; see Wallas, 1926). Engagement in creative activity has also been associated with a state of flow, which is characterized by deep immersion and subjective feelings of ease and timelessness (Csikszentmihalyi, 1997).

Many empirical approaches have been developed to enable the study of divergent and convergent thinking creativity in standardized settings. A prominent example of a divergent thinking task is the "alternate uses" task, which asks participants to find creative new uses for common objects, such as a brick or car tires. Other popular divergent thinking tasks require experimental subjects to imagine consequences of utopian situations, suggest product improvements, complete abstract figures, or produce creative metaphors, as well as humorous puns. Performances in divergent thinking tasks are usually scored with respect to quantitative and qualitative aspects. Quantitative scoring assesses the total number of responses (i.e., ideational fluency) or the number of responses from different categories (i.e., ideational flexibility) produced in a given time. Creative quality, conversely, is commonly evaluated by raters, tabulated norms, or analyses of statistical infrequency (Barbot et al., 2019; Reiter-Palmon et al., 2019). There is broad consensus that a creative idea has to be both novel/unusual and effective/task-appropriate (Runco and Jaeger, 2012; Diedrich et al., 2015). Popular convergent thinking creativity tasks include the Remote Associates Test (Mednick, 1962), which asks to find a word that links three unrelated words, and various insight problems, such as the nine-dot problem (Gilhooly and Murphy, 2005). Besides divergent and convergent thinking creativity, also more complex creative production tasks are employed, asking to create drawings, write stories, or improvise on a musical instrument. Performances on these tasks are usually assessed by a panel of competent judges (i.e., consensual assessment technique; see Amabile, 1982). Reviews of the cognitive and neuroscience literature (Forgeard and Kaufman, 2016; Benedek et al., 2019) showed that most research explores creative idea generation (>50%), whereas less work investigates creative problem solving (10–20%) and product-based creativity (20–30%).

The availability of standardized measures of creative thinking enabled the investigation of the specific cognitive and brain processes underlying creative cognition, such as memory, control, and attention. The role of cognitive control in creative cognition has been a vexing problem as there is evidence for the relevance of both controlled, goal-directed, and spontaneous, undirected processes (for reviews, see Chrysikou, 2018; Benedek and Jauk, 2019). While active creative thinking benefits from effective strategies and high cognitive capacity, spontaneous processes may be particularly relevant for more complex creative work that runs into impasses and involves incubation phases (for dual process accounts of creative cognition, see Sowden et al., 2015; Benedek and Jauk, 2018). Neuroscience research has begun to shed light on the neural basis of creative cognition, which heavily relied on functional MRI (fMRI) studies on musical improvisation (Bengtsson et al., 2007; Berkowitz and Ansari, 2008; Limb and Braun, 2008; de Manzano and Ullén, 2012; Pinho et al., 2015; for a review, see Beaty, 2015). Musical improvisation was found to implicate brain regions of the executive-control network (ECN) and the default mode network (DMN). These networks were further shown to exhibit increased functional coupling not only during piano improvisation (Pinho et al., 2015) but also in poetry composition (Liu et al., 2015) and divergent thinking (Beaty et al., 2015). The ECN is typically involved in top-down control, whereas the DMN is mainly implicated in self-generated thought, which can be spontaneous as in mind-wandering, or goal-directed as in mental navigation (Andrews-Hanna et al., 2014; Christoff et al., 2016). The coupling of these large-scale brain networks during creative cognition is thought to reflect an interplay between controlled, evaluative and more undirected, generative processes (Beaty et al., 2016; Zabelina and Andrews-Hanna, 2016). Additionally, the salience network (SN), which is considered to be implicated in the dynamic transitions between DMN and ECN (Uddin, 2015), may contribute to creative thought by forwarding candidate ideas originating from the DMN to the ECN for high-order processing, such as idea evaluation (Beaty et al., 2015). A recent study has demonstrated that creative people have the ability to simultaneously engage these large-scale brain networks (Beaty et al., 2018a), suggesting that individual differences in the ability to simultaneously engage DMN, ECN, and SN regions can be viewed as a neurophysiological marker of creativity (for reviews, see Beaty et al., 2016, 2019).

The role of memory in creative cognition is similarly fascinating, as creative thinking is known to build on memory and yet must go beyond recall in order to create something new. Creative thought has been conceived of as a fruitful recombination of remote associative elements (Mednick, 1962), but it is an ongoing debate to what extent it relies on a more effective access to memory and/or a deviant organization of memory (Kenett et al., 2014; Benedek et al., 2017a). Neuroscience research revealed that both semantic memory and episodic memory play a chief role for creative cognition (e.g., Fink et al., 2015; Madore et al., 2015). It is important to note that episodic remembering represents a reconstructive process, and that there is increasing evidence that episodic memory networks (overlapping with the DMN) are also recruited during future thinking and creativity (Beaty et al., 2018b, 2020; for a review, see Schacter et al., 2012). Still, the generation of creative new ideas slightly differs from the recall of known original ideas in additionally recruiting the left anterior inferior parietal cortex, which again points to the involvement of executive processes for integrating memory content in new ways and supporting executively demanding mental simulations (Benedek et al., 2014b, 2018).

Creative cognition has been further variably associated with broad, leaky, defocused or focused attention (Zabelina, 2018). There is at least some consensus though that imagination involves internally directed attention. When we imagine something new, indeed, we usually ignore or suppress irrelevant sensory input (for a review, see Benedek, 2018). This internal focus of attention has a clear neurophysiological signature as evidenced by eye-behavior changes reflecting perceptual decoupling and visual disengagement (Annerer-Walcher et al., 2018), increased electroencephalogram (EEG) alpha activity especially in the frontal and right parietal regions (Benedek et al., 2014), and reduced visual network activity paired with increased right parietal brain activation (Benedek et al., 2016). Increases of EEG alpha activity are a particularly robust finding in creativity research (Lustenberger et al., 2015; Luft et al., 2018; Agnoli et al., 2020; for reviews, see Fink and Benedek, 2014; Stevens and Zabelina, 2019), representing inhibition of task-irrelevant (sensory) processing (Jensen et al., 2012; Klimesch, 2012), which appears crucial for sustained internally directed activities involving imagination and mental simulation. Indeed, musicians were found to exhibit increased frontal upper alpha-band activity during musical improvisation compared with rote playback (Lopata et al., 2017); in contrast, more accurate learning of new musical structures was associated with lower alpha power, potentially suggesting that less internal focus is necessary when retrieving more automatized procedures (Zioga et al., 2020). Musical learning was also associated with increased amplitude of relevant event-related potentials (ERPs; for a review of early EEG/ERP findings, see Dietrich and Kanso, 2010).

In all, creative thinking is increasingly understood in terms of a specific configuration of underlying memory, control, and attention processes and their neural substrates (Jung and Vartanian, 2018; Benedek and Fink, 2019). This set of neurocognitive functions generally endows people with the capacity to engage in creative thinking. Yet, people still differ considerably in their creative task performance and creative lifetime accomplishments. It is the central mission of individual differences research of creativity to explore the range and reasons of this variability and to understand how differences in creative potential eventually lead to differences in real-life creative achievements. Available models assume that creative achievement relies, on the one hand, on the cognitive potential to think creatively and, on the other hand, on conative factors, such as personality, expertise, and environmental conditions (Amabile, 1983; Eysenck, 1995). Creative personality is associated with high openness to new experiences (Feist, 1998) as well as high intrinsic motivation to engage in creative behaviors (Benedek et al., 2020a). Beyond what has been traditionally labeled as everyday creativity, more professional forms of creativity crucially rely on high domain-specific expertise (Weisberg, 1993; Boden, 2004; Kaufman and Beghetto, 2009): one must know the tools and rules of a given domain very well to extend, re-develop, or eventually break them in creative ways. Research has also identified environmental factors that are conducive to creativity including stimulating others, supportive structures, or general *zeitgeist* (Amabile, 1983; Simonton, 1999). In the next section, we will present research that goes beyond the individual perspective introduced here to explore creativity at a group, or system, level.

A Collective Perspective on Creativity

While we sometimes associate creativity with eccentric scientists or lone composers who withdraw themselves from society until their work is done, creativity is not always understood as a solitary activity. In fact, complex creative work typically relies on collaboration between experts from different fields, and creative performances often require an ensemble or team of contributors. Moreover, creative work develops and exists in the wider context of its sociocultural environment and specifically its recipients (Glăveanu, 2014). The effects of such an ecological dimension have been acknowledged in relevant theories of creativity: the four P model (Rhodes, 1961) speaks of *press* (referring to the relationship between creative agents and their environment), besides person, process, and product; the five A-model (Glăveanu, 2013) speaks of *audience*, besides actor, action, artifact, and affordances; and many other models highlight how creative activity takes place within, and is shaped by, its social and organizational settings (e.g., Amabile, 1982; Eysenck, 1995; Amabile and Pratt, 2016).

The empirical study of group creativity has traditionally looked at how creators interact, how different social conditions affect creative outcomes, and how people judge the creative work of others. Much attention has been devoted to the investigation of creative idea generation in groups (aka brainstorming). Brainstorming was thought to boost creative performance by harnessing the power of cognitive stimulation and increased motivation when people interact (Osborn, 1963). Closer investigation, however, revealed that groups often perform poorer than nominal groups (i.e., an equal number of individuals performing tasks individually yields higher total performance;

Diehl and Stroebe, 1987). Different cognitive, affective, and motivational process losses have been identified to occur when people generate ideas together, including production blocking (i.e., idea generation is blocked for all but the one who speaks), evaluation apprehension, pressure for conformity, and free-riding tendencies (Pinsonneault et al., 1999; Dugosh and Paulus, 2005). Idea generation in groups thus involves process gains and losses, and better outcomes have been associated with moderate group sizes and a balance between individual and interactive performances, such as those realized in brainwriting and electronic brainstorming (De Rosa et al., 2007).

Creative behavior is also affected by the attitude and feedback of others. While creativity is generally viewed as desired and needed, people often tend to reject novel, creative ideas due to their unfamiliarity and uncertainty (Mueller et al., 2012). In a similar way, it has been shown that teachers usually value creativity in students, but do have reservations when working with students who show creative traits, such as non-conformity and disagreeableness (Scott, 1999). Creativity further relies on the intrinsic motivation to generate and on creative self-concept (Amabile, 1985; see also Karwowski and Kaufman, 2017); yet, extrinsic factors, such as creativity-contingent positive and task-focused performance feedback, can also support creative performance (Byron and Khazanchi, 2012). Inflated praise, however, can have adverse effects, such as encouraging to go for low-hanging fruits instead of meeting challenges that involve higher risks (Brummelman et al., 2014).

As human behavior is always embedded in a social context, creative activity is clearly shaped by social dynamics, usually in the form of explicit interactions and implicit expectations by others. Along these lines, a number of scholars now maintain that because self and society (i.e., individuals and groups, living systems, and environments) form a structured unity, any attempt to decouple its constitutive elements may give rise to only partial representations of the creative phenomenon (Gergen, 1994; Montuori and Purser, 1999; Sawyer, 1999). Here, further insights arise from attempts to reconcile individual and collective elements in multimodal approaches (Amabile, 1996). As we will see later on, music and musical practices are good examples of this. In this field, individuality and collectivity are often seen as complementary aspects of one's musical life, providing together more than just a sum of their respective domains (see also Olivetti Belardinelli, 2002). This may have crucial implications for our understanding of musical creativity and for creative cognition more generally. Before engaging with this issue in more detail, however, we first wish to illustrate the rationale behind the second dichotomy we have previously individuated—that between domain-general and domain-specific perspectives on creativity.

Domain-Generality, Domain-Specificity, and Music

Creativity can be observed in diverse contexts and at various levels of professionalism: designing a decoration or a spaceship, improvising in the kitchen or on stage—all are thought to rely on creativity. The large diversity of creative behaviors has motivated researchers to organize them into different boxes. On a quantitative level, a distinction is usually made between little-c, pro-c, and big-c creativities, which refer to everyday, professional, and eminent creativities, respectively (Kaufman and Beghetto, 2009). On a qualitative level, creative behaviors have been sorted into different creative domains. As Sternberg argues, however, "[t]he greatest challenge in understanding the domain-generality vs. specificity of creativity is in understanding the concept of a domain itself" (Sternberg, 2009, p. 25). Creativity tests are mostly distinguished into verbal and figural tests and less frequently include numerical and musical tests, based on its response modality (see Torrance, 1974, 1984). A closer examination of the neurocognitive processes involved in task performance, however, suggests that this distinction is not fully valid (Benedek and Fink, 2019). For example, the alternate uses task, a popular divergent thinking task, requires to find and write down creative uses of everyday objects and thus is considered a verbal task. Process analyses of task performance have revealed that a commonly adopted strategy is to mentally disassemble the object and create novel products from its parts (Gilhooly et al., 2007), which requires a visual representation of the object and mental simulation of how its parts can be meaningfully reassembled. The solution could actually be drawn as well, but providing verbal responses simply appears most convenient. Neuroscience research has offered further evidence that "verbal" creativity tasks substantially implicate visual and motor regions (Benedek et al., 2020b; Matheson and Kenett, 2020), suggesting that creative task performance relies on multimodal capacities. Hence, the classification of tasks by their response modality may tell us a little more than how ideas are expressed in the final step of ideation (Benedek, 2018), but it does not adequately capture the complexity of the underlying neurocognitive processes. Given the available evidence, and the highly associative, multimodal organization of our brain, it could even be questioned whether there exists something like a pure verbal or visual creativity task, challenging narrow conceptions of task domains.

Quite different classifications of creative domains are used at the level of creative behavior and achievement. A very basic distinction can be made between arts and sciences (Feist, 1998). More fine-grained categorizations consider several domains, such as literature, music, visual arts, performing arts, culinary arts, humor, architecture, as well as creativity in business, sports, sciences, or social contexts (Carson et al., 2005; Abraham, 2018; Diedrich et al., 2018). These domains attempt to capture the most common creative behaviors, and follow established organizations of education tracks and professions relevant to creativity. However, any domain classification will fall short to comprehensively cover and represent the vast range and ideocracies of creative expression. It is in the very nature of creativity to extend established structures, and creativity thrives most when boundaries are crossed (Shmailov, 2016). Task modalities and creative domains should thus not be understood as natural entities, rather, they point to certain conceptual differences that may prove useful to organize thought and research, highlighting the diversity of creative behavior in general.

These considerations well exemplify the distinction between domain-general and domain-specific views on creativity (Baer, 2015; Barbot and Tinio, 2015). The problem gravitates around the question of whether creativity observed across different domains relies on common cognitive resources or rather on different specialized capacities. Put simply, "the theory that creativity is domain-general [. . .] predicts positive correlations among the levels of creativity exhibited by individuals in different domains. Domain specificity predicts the opposite" (Baer, 2012, p. 19). The latter conception may imply that we may need not just one, but many theories that examine creative thinking and behavior in different contexts. A promising candidate for a domain-general aspect of creativity is divergent thinking. As mentioned earlier, the latter refers to the process of coming up with creative ideas, which appears fundamental to all forms of creative expression. In fact, there is substantial evidence that divergent thinking ability plays a role for various domain-specific forms of creativity. Divergent thinking ability was shown to predict the creativity of humor production besides intelligence (Kellner and Benedek, 2017), as well as mathematical creativity besides mathematical competence (Schoevers et al., 2018). Divergent thinking ability also predicts creative life-time achievements assessed by self-reports across domains, especially when estimating latent correlations (Plucker, 1999; Jauk et al., 2014). Studies focusing on specific domains reported that divergent thinking ability predicted the level of creative accomplishments in advertisers (Agnoli et al., 2019) and the quality of improvisations in jazz students (Beaty et al., 2013), and was higher in professional dancers than in novices (Fink et al., 2009). Divergent thinking ability even distinguished between subdomains, as evidenced by higher creative potential in jazz musicians than in folk musicians (Benedek et al., 2014a). Other studies, however, found no relationship between divergent thinking ability and domain-specific creative accomplishments in a domain (e.g., film artists; Benedek et al., 2017b), which could partly be explained by the fact that highly accomplished artists sometimes show little compliance to participate in psychological tests of creativity. Further evidence comes from the analysis of self-reports of creativity. These self-reports tend to correlate substantially with people's self-concept of creativity (Kaufman and Baer, 2004). Similarly, latent-class analyses of self-reported accomplishments revealed that people differ in the level of creativity rather than in creative domains (Silvia et al., 2009). These findings are consistent with the domain-general view of creativity, but it needs to be noted that they relied on convenience samples, such as university students who commonly do not exhibit very high levels of creative achievement.

The domain-specific view of creativity is typically supported by noting that relationships between divergent thinking ability and creative accomplishments are very low (Baer, 2015). Moreover, it is generally questioned whether eminent creative people, such as Albert Einstein, would have been equally successful in other domains, such as poetry (Kaufman and Baer, 2004). These questions are hard to test empirically, but many creative geniuses have in fact been polymaths, and there is evidence especially for a fruitful relationship between engagement in arts and scientific success (Root-Bernstein et al., 2008). Yet, it appears undisputed that the role of domain-specific expertise increases with more professional levels of creativity (Kaufman and Beghetto, 2009). Arguably, a person without any training in a given field (e.g., medicine, violin performance, etc.) will not be able to make substantial contributions to her respective field. From a domain-general perspective, the question remains whether a person with poor creative abilities could ever make substantial creative contributions to any area.

How do these deliberations apply to musical creativity? Generally speaking, music has fascinated neurocognitive research because "playing, listening to, and creating music involve practically every cognitive function" (Zatorre, 2005, p. 312), and it is often associated with strong emotions and experiences (Gabrielsson, 2001; Jäncke, 2008). Musical practices have also recently drawn the attention of scholars interested in their creative properties, as well as in the creative potential of those who engage with them, giving rise to a large number of interdisciplinary contributions situated at the crossroads of musicology, cognitive (neuro)science, as well as sociological and psychological research (see e.g., Burnard, 2012; Donin and Traube, 2016; Clarke and Doffman, 2017; Cook, 2018). And indeed, music is among the most popular domains in inventories of creative achievement (Diedrich et al., 2018). Interestingly, measures of creative cognitive potential do not really cover musical expression. There have been approaches to assess the potential for musical creativity in terms of basic abilities to generate novel melodies or rhythms in non-musicians (Berkowitz and Ansari, 2008), but it is more common to study musical creativity in professionals and in the moment-to-moment realization of their artistic outcomes. In the next section, we pick up a related thread as we focus on the contexts of music performance and music composition. Our aim is to critically engage with existing research and theory, assess a number of empirical findings, and show how individual and collective forms of creativity can be synergistically integrated. Among other things, we offer a novel interpretation of the results from an fMRI study by Lu et al. (2015). More specifically, we suggest that because the body of work we discuss in the following lines treats singular and plural creative dynamics in a flexible way, it challenges more static views that often characterize current creativity research.

MUSICAL CREATIVITY BEYOND *SOLO* AND *TUTTI*

The study of musical creativity offers a good example of a research avenue that increasingly looks beyond the polarization of individual and collective perspectives to embrace a more unitary view—one that sees singular and plural dimensions of creative cognition as two sides of the same coin. Additionally, because music involves a vast range of culturally relevant experiences, behaviors, products, and entanglements, it constitutes an ideal field of enquiry to look at both discrete and wide creative competences: while musical practices are specific enough to be characterized by precise norms and conventions across different social contexts, they also disclose a theoretically unlimited variety of possibilities to extend existing artistic knowledge. Musical activities, as we will see more in detail later on, are also associated with a range of general cognitive capacities, making the analysis of domain-specificity and domain-generality particularly fascinating. The present section addresses these and other insights within two main musical areas taken as exemplary domains: performance and composition.

Performing Music

When thinking about creative musical performance, probably the first thing that comes to mind is an improvising jazz ensemble (see e.g., Johnson-Laird, 1988; Sawyer, 1992; Bailey, 1993; Berliner, 1994; Wilson and MacDonald, 2017). It is easy to imagine group members engaged in free improvisation or taking turns to produce subtle expressive nuances while repeating the main theme, collaboratively changing tempo, accents, and beats, and developing melodic, harmonic, and timbric mutations. Expert improvisers, indeed, are known to transform performance into a process of mutual discovery and negotiation, where different motor, communicative, and imaginative parameters are dynamically generated, assembled, hybridized, and re-deployed to serve novel functions and guide their activity through known and unknown (musical) territories (see Murray, 1998; Doffman, 2009; Duby, 2018; Kimmel and Rogler, 2018; Kimmel et al., 2018; van der Schyff, 2019).

Seminal research by Sawyer (2003, 2006), among others, placed major emphasis on the emerging dynamics involved in the generation of creative action when groups of individuals cooperate. Specifically focusing on jazz musicians and artists devoted to improvisational practices, Sawyer conceived of interaction itself as the main locus of creativity. As reported by van der Schyff et al. (2018), the latter in such contexts (i) displays an unpredictable outcome, (ii) involves a moment-to-moment contingency where each person's action depends on the one just before, (iii) remains based on an interactional effect where any given behavior can be changed by the activity of other participants, and (iv) is intrinsically collaborative (Sawyer and De Zutter, 2009, p. 82). Notably, such insights do not only apply to (joint) improvisational settings; they are also relevant to broader situations in which musical interaction unfolds at different levels and timescales. To gain a richer understanding of how these considerations may be applied to concrete musical contexts, in what follows, we present cases involving online and offline adaptations between composers and performers, joint musicking, and instances of solo music-making. This can help us develop a constructive dialogue between theoretical insights and real-life musical practices, showing how individual and collective creative dynamics can be strongly intermixed. The florid interplay of solo and group aspects in creative music-making that emerges from this discussion also anticipates later comparisons between domain-general and domain-specific creativities[1] and motivates the testable hypothesis we present in the conclusive section.

[1]As we will see in "The Ubiquity of Skillful Adaptation" section, there is an important sense in which basic bio-cognitive properties of living systems can be described in terms of organism–world co-specification, thereby including social dynamics into individual processes.

For now, let us begin with a comparison between the verbal communication occurring between musicians, composers, or improvisers when planning, rehearsing, optimizing, or simply sharing information about a novel piece or performance (see e.g., Clarke et al., 2013, 2016; Biasutti, 2015, 2018) and the online patterns of non-verbal interaction and self-regulation exhibited by members of classical ensembles (see e.g., Davidson and Good, 2002; Biasutti et al., 2016). In both cases, outcomes can be hardly predicted with precision: complaints or suggestions voiced by instrumentalists regarding particularly complex musical configurations, for example, may change the composer's initial plans in various ways, giving rise to a series of adaptive, constructive dialogues, in which a middle ground between the composer's expressive needs and the performative constraints indicated by the performer is generally reached[2] (see Doffman and Calvin, 2017; Whittall, 2017). Importantly, members of a music ensemble executing a piece (e.g., from the Western classical repertoire) are also subject to constant adaptive changes. As reported by Bishop (2018), co-players often employ anticipatory strategies to keep various musical parameters, under control thereby optimizing their joint performance (see also Bishop et al., 2013). An EEG study by Loehr et al. (2013), for example, showed that expert pianists can selectively monitor their own actions and those of their partner, anticipating individual and combined musical outcomes. Along these lines, Badino et al. (2014) quantitatively examined *via* Granger causality[3] the coordination dynamics of string quartet members during normal and perturbed conditions, finding that more demanding musical passages necessitate more reciprocal interaction and mutual influence from the performers than less challenging sections. Singular and plural factors of performance, on this view, must be continuously monitored, transformed, and negotiated in a process of adaptation and mutual interaction.

Working collaborations between composers and performers, as well as online interactions within groups of musicians, illustrate well the spectrum of reciprocal dependencies involved in music-making. For example, performers and composers can cooperate to explore a particularly innovative solution by creatively re-defining the horizon of opportunities for action of a musical instrument: strings can be untuned, pianos can be "prepared," tools and technologies can be adapted for various expressive necessities, and so forth. This can lead the interactors to challenge each other, build on their expertise, and develop novel creative synergies to redirect individual plans toward different outcomes (Sawyer, 2003). With regard to the online interactions within a performing ensemble, a further example may help. Consider here the cascade of changes and adaptations

[2]Methodologically, analyses of this joint activity often rely on historically informed research, in which correspondence letters between composers and performers are examined and put into context. Examples can be found in the missives exchanged by renewed classical guitarist Andrés Segovia (1893–1988) and the composers (e.g., Manuel Maria Ponce, Mario Castelnuovo-Tedesco, etc.) who did heed his call to write new pieces for guitar to make the latter's repertoire blossom. "Many of these composers, [. . .] were not familiar with the classical guitar, and it was necessary for Segovia to collaborate with them in order to make the music playable" (Knapp, 2011, p. 2).

[3]This is a "a measurable concept of causality or directed influence for time series data, defined using predictability and temporal precedence" (Roebroeck, 2015).

that even a simple shift in a musical parameter may give rise to: imagine how a rock band playing their most famous song during a live show may unintentionally slow down the chorus to facilitate the audience singing along, thus impacting the coordination dynamics between group members. Because availability of visual cues facilitates interaction and successful synchronization among co-performers (see Bishop and Goebl, 2015, 2018), musicians might move across the stage more than expected to optimize their visual communication. This unpredicted change of plans might disrupt the fluidity of their execution (as well as the visual impact of their live performance) particularly during the lead guitarist's solo occurring after the chorus: away from her multi-function pedalboard, she could not use her favorite effect (say, wah-wah). To compensate for this loss, the bass player, so the story goes, decides to accompany the solo with unexpected high notes, generating new fascinating counterpoints on the spur of the moment. This vignette resonates with early insights from Jane Davidson, who maintains that "if the performer senses the many cues of the live performance context and interprets them positively, a new state of psychological awareness can be achieved which allows the individual to become both highly task-focused and able to explore spontaneous thoughts and feelings in a creative manner" (Davidson, 2002, p. 149).

More in general, these examples are offered to situate the initial insights on improvisation within a broader understanding of performative creativity as an adaptive phenomenon that plays out in situation of online and offline collaborations. In such contexts, one can observe a continuous interplay of individual and collective decisions, plans, memories, choices, feelings, behaviors, and musical ideas, and how these can be recursively re-organized and adapted at both personal and multi-personal level. This well aligns with work on creative thinking that explores the deep connections between control, memory, and attention (Benedek et al., 2016), highlighting the social side of these categories.

Remarkably, there is also an important sense in which these considerations speak to situations where subjects make music alone, by themselves. Indeed, recent work in the field has highlighted the compenetration of solo and joint aspects of musical practice, suggesting that individual settings are, in fact, intrinsically collaborative (see e.g., Høffding and Satne, 2019; see also Cuffari et al., 2015 for similar insights developed with respect to language). This work provides an apt counterpoint to research that focuses on more explicitly interactive creativity–where collective outcomes are conceived of as emergent properties of the joint effort of collaborating agents–and complements existing studies that engage with lone individuals and their solitary creative achievements (e.g., solo improvisation). Looking for "traces" of intersubjectivity within solo musical contexts, accordingly, could reveal how individual activity might be understood as inherently participatory, shedding in turn new light upon both solo and plural forms of performative experience and their creative manifestations (see also Frith, 1996; Folkestad, 2012; Loaiza, 2016; Cook, 2018). Albeit not generalizable, qualitative data recently collected with expert and novice musicians (Schiavio et al., under review) indicate that playing music in isolation often involves a felt presence of others based on the creative re-enactment of a shared repertoire of practices or an anticipated experience of music-making in context. The latter refers to situations in which "virtual others" are mentally constructed or imagined by solo performers (e.g., when rehearsing at home a piece for orchestra); the former condition, in which a social presence is reported to be perceived in solo musicking, is more difficult to address. Perhaps, it could be argued that adopting certain instrumental techniques while improvising, realizing an ornament on the flute when interpreting a baroque piece, or choosing a tempo where not explicitly indicated in the score reflects an already intersubjective structure constituted by a community of practice (see Wenger, 2002)—a product of a historically sedimented creative work to which one skillfully adapts. In other words, individual musical choices and solutions are here understood as part of broader cultural, historical, and technical milieux and therefore never fully independent from their social components (see again Høffding and Satne, 2019).

In the target study (Schiavio et al., under review), two broad categories were considered: agency and creativity. Interviewed participants referred to agency (i.e., the subjective feeling that one is the author of her own actions) by describing various bodily and emotional aspects central to their musical experience, and how they may involve a sense of shared corporeality even in cases of solo practice. To provide an example, consider the following quote from an expert singer: "I always try to be as close as possible to the original intentions of the composers. This puts me in a weird place because then I must account my emotions, my sensitivity, and my fingers. It is like, I can look at the world with the eyes of the composer, but still within my own body." This self-other negotiation can also play out in more intuitive terms, and is further recognized by an expert pianist as follows: "when I rehearse by myself I can feel the composer and his intentions, yeah. I say 'feel' because there are no main thoughts here." The same focus on intersubjectivity emerged when subjects were asked about creativity. The latter was associated with terms such as "adaptation," "mutual connection," or "a need to communicate with someone." For instance, one novice stated that "creativity is linked to how I express myself, my body language, more than just making music. It is about interacting with who is around and who will eventually get in contact with what I sing and how." This study provides rich descriptions of situations in which *prima facie* "solo" creativity is associated with a more socially relevant dimension. As hinted above, this also refers to "those mutually constitutive relationships through which, as they grow older together, [people] continually participate in each other's coming-into-being" (Ingold and Hallam, 2007, p. 6, quoted in Cook, 2018, p. 9). There is thus a complex web of social factors involved in seemingly isolated musical practices[4], which permeates creative and expressive musical outcomes of individuals (and groups).

[4]This echoes insights from Eric Clarke, who suggests that music performance can be considered as "the construction and articulation of musical meaning, in which cerebral, bodily, social, and historical attributes of a performer all converge, and if we choose to regard this convergence as an expression of the performer's mind, then we must remember that the mind is neither driving the body nor confined within the head" (Clarke, 2002, p. 68–69; see also Leman, 2008).

The concrete cases of music-making we examined in this section (ranging from solo improvisation to ensemble performance) provide good examples of this broad network of factors shaping creative efforts. In the next section, we further unpack these insights and explore the adaptive interplay of individual and collective creativities in the context of music composition.

Composing Music

Creative artifacts usually take form of aesthetically rewarding products, which carefully integrate original and familiar factors in various ways. As we have suggested in the previous section, music performers can often achieve such a goal by engaging in processes of interpersonal adaptation and discovery even when playing alone. In doing so, musicians creatively negotiate (consciously or unconsciously; see Simonton, 1988; Sawyer, 1992) manifold cognitive strategies to optimize their musicking, in a constant interaction with the community of practice in which they are embedded. By exploring these strategies at different (e.g., cultural, behavioral, neural, analytical) levels, the study of musical performance–understood as a visible process of (co-)creation–can contribute a novel perspective on the collision of individual and collective factors in creative activity.

In this section, we extend these insights to the domain of music composition, starting from cases where clear-cut distinctions between performers and composers may be too static to capture important aspects of their creative effort. We then discuss more traditional examples of (score-based) compositional practices drawing on recent empirical work that looks at both qualitative and neuro-functional data, pointing again to an overlap of singular and plural dynamics. This, importantly, includes both (i) creative products and (ii) creative processes. Regarding the former, it should be noted that musical outputs are usually evaluated: whether they are generated in isolation or with others, creative forms, ideas, or contents need other people to be assessed, judged, examined, and culturally located. Indeed, "[c]reativity has a property that is not true of all psychological constructs—it exists in the interaction of the stimulus and the beholder. A maker may view his or her work as creative, but if there is not an audience that sees it that way, the maker aside, then the work is not considered creative" (Sternberg and Kaufman, 2010, p. 468). Similarly, the association of solo and joint dimensions emerges in the processes of music-making when the repertoire of actions, choices, and musical ideas at the basis of musical creation is contextualized and historically situated: as Dillon (2006) reports, with reference to Amabile (1985) and Csikszentmihalyi (1988), the social framing of creative effort involves a dialectic process of negotiation where individuals, groups, and sedimented practices form a uniquely recursive structure, often problematizing issues that go beyond the analysis of psychological processes, such as those pertaining to copyright and artistic appropriation.

The shifting constraints and goals of musical performance, thus, invite explorations and induce variabilities that are crucial for music-making (e.g., musicians deliberately inhibiting or reinforcing control and focus) and reflect larger social and cultural dynamics involving fine-tuning of musical ideas and adaptations to existing practices and repertoires (e.g., how to interpret a piece in a historically informed way without simply reproducing the score). Moreover, because repertoires and musical conventions are collectively constructed over the years by an evolving community of practitioners[5], there is a strong sense in which even individual creative musical actions emerge from, and embody, such a web of relationalities. This insight prompts us to rethink the traditionally stark differentiation–probably advocated among others by Schönberg and Stravinsky–between originators of genuine musical ideas (i.e., composers) and mere executors (i.e., performers), helping problematize the "authorial identity" of the formers (Cook, 2001, 2006). Consider the following quote from classical guitarist Pepe Romero:

> "As a player, when you take a piece of music you have to feel and become in tune with that composer, with his mind and with his soul, and unite it to your own mind, to your own soul, to your own heart. Then you can recreate the music so it has a freshness, and it sounds when the player plays it like he is composing it also. Together [the composer and the player] make one and they merge together; you cannot tell where one begins and the other ends. I know that when I play, and the music is really flowing, I cannot tell the difference between the composer and myself" (quoted in Dobrian, 1991).

We have already seen how composers and instrumentalists often combine divergent and convergent thinking when collaborating, for example, when exploring together multiple musical possibilities to optimize a planned performance, and evaluating all alternatives through analysis, trials, and processes of mutual adaptations (see Webster, 1987; Wong and Lim, 2017). However, the quote above points to a more intimate synergy, which plays out during the act of musicking. While this context-dependent "fusion" between composer and performer reminds of situations of improvised or vernacular musical contexts, in which "the power relationships among those taking part are diffuse, uncentralized; all will have some authority and bear some responsibility" (Small, 1998, p. 115), it also runs deep in Western classical settings. Consider, for example, how the *re-creation* of a musical score through interpretation becomes a legitimate *creative* process when it involves an artistically significant, innovative output—a feature that has been somehow downplayed by more traditional accounts:

> "[M]usic affords an apparently unlimited variety of interpretive options, and we could be much more adventurous in our exploration of them if our thinking about performance was more flexible. The idea of music as sounded writing gives rise to what [. . .] I call the paradigm of reproduction: performance is seen as reproducing the work, or the structures embodied in the work, or the conditions of its early performances, or the intentions of its composer. Different as these formulations are–and the last can serve as a justification for almost anything–they all have one thing in common: no space is left for the creativity of performers" (Cook, 2013, p. 3).

[5] For example, empirical work by Repp (1997) suggests that the generally preferred style of rubato is basically the average of what most performers are doing today. This is presumably different from rubato at the time the work was composed (see also Parncutt, 2003; Bisesi et al., 2019).

Given this emerging overlap of roles, one could wonder whether the recognition of performers as creators would somehow downplay the creative authority of composers. Data from another recent qualitative study (Schiavio et al., 2020) indicate that Western classical composers are generally well aware of the relational dynamics involved in their "solitary" creative effort. While there has been some resistance to adopt this methodology to explore creativity in composers and musicians (Juslin, 2019, pp. 31–32), we maintain that a first-person approach has the advantage to offer unique insights into their lived experience, providing concrete descriptions grounded in the respondents' everyday musical activities. Comparably to performers, composers seem to benefit from the florid mixture of individuality and collectivity in generating creative ideas, referring to three inter-related aspects of their compositional experience: (i) the instantiation of an adaptive dialogue between themselves and their social and cultural environments (e.g., composers from the past, future audience, performers who will play the piece they are composing, etc.), (ii) the importance of an explorative drive informing their practice, and (iii), the physicality of their musical activity, that is, how body and action take part in shaping creative ideas and outcomes, particularly when directed toward specific musical instruments. In all, this may help us cast a new light on what internally directed attention entails in similar activities. Rather than a lack of focus on external information, it rather requires a continuous integration of internal and external dynamics, and involves what Nagy refers to as a "constant, parallel evolution of both creative awareness and activeness" (2017, p. 34). This decenters the creative locus from the individual to a uniquely developing organism–world system (more on this below).

The ranges of responses collected in this qualitative work also partly align with a recent fMRI study with 17 music composers conducted by Lu et al. (2015). Here, the researchers compared the participants' functional networks during an imaginative compositional task (after looking at a page with one written bar of music) with resting states (measured before the task). Two main results were found: during the composing period, participants exhibited a decreased functional connectivity between visual and motor areas and a stronger functional connectivity between the anterior cingulate cortex (ACC) and the DMN. The authors discuss the former result in terms of instrument-specificity: all composers were asked to create music for an instrument they did not know how to play (i.e., the Chinese Zheng); the second result, instead, suggests a context-dependent integration of emotional, combinative, and evaluative processes sub-serving how participants mentally manipulated sounds to convey emotions. We could speculate that this latter outcome also points to a "hidden" social dimension: sub-regions of the ACC (particularly its dorsal component) exhibit functions involved in the detection and appraisal of socially oriented (e.g., emotional) information (see e.g., Behrens et al., 2009; Apps et al., 2016), complementing existing evidence that implicates the ACC in the adaptation and monitoring of online motor activity (see Hochman et al., 2014; Mado Proverbio, 2019). Similarly, the class of midline and lateral cortical areas known as DMN (Andrews-Hanna et al., 2010, 2014)–whose activity has been usually associated with both mind-wandering states (Gould van Praag et al., 2017) and self-focused attention (Raichle et al., 2001)–"has been shown to play a critical role in various aspects of human social behavior" (Saris et al., 2020). In particular:

> "The medial temporal DMN subsystem is associated with recollection of experiences and autobiographical processing, and is comprised of the hippocampal formation, retrosplenial cortex, inferior parietal lobule, and ventromedial PFC [prefrontal cortex] [...]. The dorsal medial DMN subsystem, on the other hand, is predominantly involved in socially colored, meta-cognitive processes and mentalizing (i.e., inferences about others' internal state)"
>
> (Saris et al., 2020).

As Bashwiner (2018) notes, there is already a relatively long tradition postulating a direct correlation between DMN and divergent thinking, and therefore its implication in music-related generative ideation is not surprising (see also Beaty, 2015; Bashwiner et al., 2016; Beaty et al., 2016). With this in mind, considering both theoretical arguments and empirical data, the conjecture can be advanced that individual creative ideation in music composition reflects wider social dynamics, involving multiple neural substrates dedicated to the integration of intra-personal and inter-personal information[6].

Work in isolation, moreover, is only one manifestation of how composers create music. We have seen already how they often collaborate with performers to optimize given plans and jointly (re-)adapt musical intuitions and forms. Composer Luciano Berio, for example, admits that the "first *Sequenza* [...] was composed in 1958 for the flute of Severino Gazzelloni, and it wasn't certainly a case that in these years we were together in Darmstadt, as it wasn't a case that [for the other Sequenze] I have met the Harp of Francis Pierre, and [...] the voice of Cathy Barberian" (Berio, 1981, p. 97, *translated from Italian*). In fact, there are many practices, experiences, and behaviors associated with composing music. These range from the systematic application of mathematical principles (sometimes adopted in contemporary Western classical music) to the creative impulse of young children and infants, who extend their natural curiosity to the world of sounds and progressively organize and develop their sonic discoveries in a deliberate way[7] (see Schiavio et al., 2017). In pedagogical settings, as Burnard (2006) reminds us, research often adopts psychometric assessments of creative musical thinking (e.g., Webster, 1992; Hickey, 1995, 2000), as well as ratings of children's musical compositions (Webster and Hickey, 1995; Hickey, 1997) in both individual and collaborative settings. Another example is collaborative songwriting in adults—where teams of composers are assembled

[6]This suggestion aligns well with recent advances in "second person" cognitive neuroscience that place major emphasis on the organism–environment coupling and the interactive nature of human cognition and experience (see e.g., Hari and Kujala, 2009; Dumas, 2011; Redcay and Schilbach, 2019).

[7]According to Wiggings, such a gamut "allows us to make distinctions between conscious creation in the deliberate planning of a formalist composer, the semi-spontaneous but cooperative and partly planned creation of the jazz improviser in a trio, and the entirely spontaneous whistling in the street of the same people that Schoenberg famously hoped and failed to convince of his 12-note 'tunes'" (Wiggins, 2012).

to collaboratively create music, particularly pop songs (Bennett, 2012). This last case resonates well with approaches inspired by sociocultural and ethnomusicological insights, where the tangible result of creative doings is often thought to involve different (and sometimes invisible) hands. An understanding of musical creativity as a multiply-realized, adaptive phenomenon, however, does not entail a sole focus on groups, or explicitly collective forms of creative activity: music ensembles are formed by individuals who constantly negotiate meanings and bring forth their personal goals, emotions, and motivations, during performance or composition. Similarly, "an overemphasis on collective composition [. . .] ran the danger of mystifying creative processes into myth and making invisible the creative contributions of individuals" (Hill, 2018, p. 100).

Instead, our analysis highlights the fluid integration of Persons (creators), Processes (thoughts and actions), Products (artifacts), and Press (cultural contingencies) in the creative musical moment (Rhodes, 1961). Musicians operate and generate artistic outputs in a living culture where solo and joint dimensions are tightly related and often hardly distinguishable. Accordingly, we have examined how individual and collective perspectives are intertwined in cases of score re-creation (i.e., by performers) and offered examples of more canonical acts of music composition (i.e., work in isolation) displaying intrinsically social components. The material discussed in this section points to an understanding of creative musical practice as a process of continuous, adaptive negotiation between individual and collective factors. This suggests that a research strategy that posits an initial distinction between these two levels might be necessarily limited. In what is next, we ground these insights into a broader framework–that of enactive cognitive science–and explore the links between adaptiveness, creativity, and mental life more generally.

THE UBIQUITY OF SKILLFUL ADAPTATION

In this section, we examine what enactive cognitive science can offer to creativity research, with particular regard to the issue of domain-generality *vs*. domain-specificity. We begin by recognizing that not only does skillful adaptation play a crucial role in creative musical practice (as we saw above); instead, it also enables the development of more general organism–world couplings—a basic bio-cognitive capacity that characterizes living systems of different degrees of complexity. We individuate two important features of such couplings: *functionality* and *novelty*. These latter, on this view, are thought to lie at the same time at the heart of creative cognition (Runco and Jaeger, 2012) and of mental life more generally; in both cases, they contribute to the construction and maintenance of meaningful relationships between living systems and their environment in which local and global dynamics are fluidly integrated. We conclude that strong differentiations between domain-general and domain-specific creative activities cannot be drawn with accuracy. Said differently, we argue that (i) what we usually describe as domain-specific creative effort relies on a more general tendency to establish novel and functional relationships with the world; (ii) but because the various concrete manifestations of such a tendency (the patterns of adaptations enacted by each living system, the value and significance from which such couplings originate and contribute to develop, etc.) reflect self-organized adaptive strategies and needs vis-à-vis an ecology, it would be rather hard to provide more general classifications. Accordingly, we propose that the distinction between domain-specificity and domain-generality can be mitigated and reframed in terms of skillful adaptation.

Adaptiveness as Novel and Functional World-Making

An understanding of musical creativity as an adaptive phenomenon integrating individual and collective dynamics, as we saw, places its visceral and participatory components at the heart of creative activity: this trades the focus on innate talent or divine gifts[8] for a perspective that locates creative behavior and thought in openness, action, and uncertainty. Openness refers to the relational nature of adaptation, which is by definition organized around at least two elements (e.g., a performer and a composer, an organism and its niche, etc.) who participate in an ongoing dialogue; action here defines the capacity of agents to establish, transform, and extend such relationships in situations of online and offline (e.g., imaginative) interactions. Because of their openness and constantly shifting nature, the formed networks are subjects to continuous internal and external perturbations, involving processes and outcomes that are largely precarious and uncertain.

Before we approach this insight from a perspective inspired by enactive cognition, we note that recent work in neuroscience has increasingly explored the neurocognitive dynamics involved in prediction and minimization of uncertainty (see Friston, 2010). Here, a central idea is that rather than passively obtaining external information, the brain is thought to be able to estimate variances and uncertainties of sensory data by endlessly producing probabilistic models of the external world (see also Kolossa et al., 2015). Put simply, the view holds that the brain can be understood as a predictive machine that aims to minimize its prediction error (i.e., the difference between predicted and actual sensory events). This view, *prima facie*, appears to be unbridgeable with the study of more creativity-prone states, which on the contrary would include increased cognitive demands for novelty seeking and exploration. As Clark (2016) put it: "[t]he cognitive imperative of prediction error minimization, it is sometimes feared, is congenitally unable to accommodate such phenomena, offering instead a prescription

[8]"If we take seriously the dictionary definition of creation, 'to bring into being or form out of nothing', creativity seems to be not only beyond any scientific understanding, but even impossible. It is hardly surprising, then, that some people have 'explained' it in terms of divine inspiration, and many others in terms of some romantic intuition, or insight" (Boden, 1998, p. 15). A good example of this can be found in the mystical aura that often surrounds Western classical composers and performers whose creative genius has been traditionally associated with innate talent (see e.g., Montuori and Purser, 1995). This stereotypical view has perpetuated, and legitimized, a still pervasive characterization of "great" Western composers–"since the rest do not make into the myths" (Cook, 2018, p. 73)–as heroic creators who can channel into music divine inspiration and knowledge (see Cook, 2006; Hill, 2018).

for quietism, deliberate cognitive diminishment, (perhaps) even fatal inactivity!" (p. 262). As we read in the very next line, however, "this worry (though important) is multiply misguided" (Clark, 2016). In fact, living systems must continuously *act* to survive and flourish as situated agents. This crucially involves forming and dissolving couplings with the environment that are both context-sensitive as well as temporally and socially extended. Not only can prediction error be minimized by means of generating more accurate ways of sensing the future, but it can also be minimized when we exert causal influence on a given event, actively changing the latter to accommodate our prediction (see Friston et al., 2010).

For these organism–world relationships to be meaningful, functionality and novelty are essential: when interaction is not functional, as sometimes it happens during a musical performance, then a satisfactory overall product will not be likely achieved: musicians playing together may just not feel like they have a good "connection" with other performers or with the audience, resulting in unsatisfactory outcomes. Interaction also needs to include innovative features, otherwise its products will likely feature static, boring, or unexciting musical moments. Importantly, because we have suggested that interaction is pervasive of musicking even in the context of solo performance or composition, these empathic connections are not overshadowed when other participants are absent. In fact, in such cases, the lack of online interaction may be compensated by imaginative strategies (e.g., the composer thinking about how an audience will react to her own new piece), by a subtler "felt" presence of others, as observed in previously reported empirical studies, and by the sets of sedimented historical norms and social conventions that endow musical practices with their different recognizable statuses across cultures and communities. As we also saw earlier, the development and maintenance of such relationships require a constant negotiation of singular and plural dynamics: goals, actions, emotions, and musical ideas of lone agents may be skillfully transformed and re-adapted on the basis of newly established couplings and social needs. In brief, in their manifold experiences and manifestations, performing and composing music involve an interpenetration of individual and collective dynamics crystallized in cognitive relationships that are novel and functional or, indeed, *creative*. Interestingly, the same tension between internal and external factors observable at the basis of these forms of music-related organism–world couplings can be found in the set of homeostatic/allostatic self-regulatory activities living systems adopt to survive, develop intelligent behavior, and preserve their structural organization (i.e., to maintain the functional unity of the system, see Maturana and Varela, 1980). The recognition of a continuity between music and these bio-cognitive activities moves our discussion toward an analysis of wider creative properties.

Adaptiveness is a fundamental aspect of our life and rests at the core of enactive cognitive science, a framework that looks at mental activity as a process of organism–environment co-specification (Varela et al., 1991; Gallagher, 2017; Di Paolo et al., 2017). Enaction is an interdisciplinary school of thought that brings together scholarship in theoretical biology, artificial intelligence (AI), cognitive psychology, phenomenology, as well as neuroscience and consciousness studies, among others (see Stewart et al., 2010). At the heart of this approach, there is the conviction that living agents are best understood as autonomous, self-organized systems, which co-evolve (ontogenetically and phylogenetically) with their ambience *via* continuous sensorimotor loops[9] (Varela et al., 1991; Thompson, 2005, 2007). Living beings are autonomous because they are organized to survive under precarious conditions by means of self-organization—the ability to separate themselves from the environment (Di Paolo, 2005, 2009). Importantly, this is a case of *differentiation*–not to be confused with *isolation* (De Jaegher et al., 2016): the living ecology in which organisms operate discloses perceptual, imaginative, and concrete action–opportunities for the re-organization and consolidation of the agent's bio-cognitive domain. Indeed, on the basis of the latter's morphological, behavioral, and cognitive complexity, various environmental affordances can be detected and acted upon[10]. As Fuchs (2018) notes, von Uexküll anticipated such insights when defining the organism–environment complementarity as a feedback loop of receptive and effective processes—a functional cycle that allows the animal to make sense of the world through evaluation and active engagement. Because evaluation and engagement allow the living system to predict threats, foresee resources, and optimize its natural inclination toward survival and well-being, the environment becomes existentially significant. The organism is thus understood as a "sense-maker" by enactivists because its being-in-the-world relies on the actualization of a meaningful perspective over its *umwelt*. A well-known passage by Evan Thompson offers a good example of how such a concerned perspective, or identity, rests upon a dynamical interplay between the organism's autonomy, its meaning-making activity, and its entanglement with its ambience:

> "Consider motile bacteria swimming uphill in a food gradient of sugar. These cells tumble about until they hit on an orientation that increases their exposure to sugar, at which point they swim forward, up-gradient, toward the zone of greatest sugar concentration. [. . .]. [T]he way they move (tumbling or swimming forward) depends on what they sense, and what they sense depends on how they move. This sensorimotor loop both

[9]"The organism is understood here to play an active role in shaping the environment it *coevolves with*—its activities feedback into and alter the selective pressures of the environmental niche. This, in turn, affects the development of the organism, resulting in a co-evolutionary cycle that proceeds in an ongoing way" (van der Schyff et al., 2018).

[10]This last aspect recalls classic insights developed in ecological psychology, and one could thus wonder how the latter framework relates to enactive cognition. Scholars working in ecological psychology draw their influence from James Gibson and his approach to visual perception, whereas advocates of enactive cognitive science usually individuate Francisco Varela as its chief representative. As recently pointed out by Baggs and Chemero (2018), these two school of thoughts have been often considered at odds with each other, advocating seemingly opposite starting assumptions: "[e]cological psychologists have traditionally asserted a commitment to realism, while enactivism was initially developed within a constructivist, and therefore anti-realist, framework" (Baggs and Chemero, 2018). In fact, this "deep contrast" is most evident in early versions of both doctrines and has been attenuated in recent years (see Chemero, 2009).

> expresses and is subordinated to the cell's autonomy. [...] As a result, every sensorimotor interaction and every discriminable feature of the environment embodies or reflects the bacterial perspective. Thus, although sucrose is a real and present condition of the physicochemical environment, its status as food is not. That sucrose is a nutrient is not intrinsic to the sucrose molecule, but is a relational feature, linked to the bacterium's metabolism. Sucrose has significance or value as food, but only in the milieu that the organism itself enacts. Thus, thanks to the organism's autonomy, its niche has a 'surplus of significance' compared with the physicochemical environment"
> (Thompson, 2005, p. 418, quoted in Villalobos and Ward, 2015).

Autonomous agents, such as bacteria, human beings, or other animals, skillfully adapt to internal and external perturbations by bringing forth (i.e., *enacting*) a world (Varela et al., 1991; Froese and Di Paolo, 2011; Di Paolo et al., 2017; De Jesus, 2018). Enactivists argue that mental life originates in such a self-organized, world-making activity (Weber and Varela, 2002; see also van der Schyff, 2015; Schiavio and van der Schyff, 2018 for music-related insights). As we saw, there is an important topological tension between this characterization of the organism's individuality and its openness to its surroundings (Di Paolo and Thompson, 2014). Living agents realize themselves and develop their identity through their metabolic activity, whose operating structures must be separated from external perturbations. At the same time, organisms regulate this activity through exchanges of energy and information with the world they inhabit, giving rise to an adaptive loop. Notably, "[t]his regulation [...] does not mechanically react to limited sets of occurring stimuli on the basis of the statistical repetition of previous experiences, but also flexibly prioritizes between novel contingencies based on their contextual relevance for the survival of the organism, anticipating the incoming changes" (Cappuccio and Froese, 2014, p. 6).

Living systems, therefore, must create organism–world couplings that are *functional* and conducive to survival. To do so, these couplings often need to be *innovative*: the constant reframing of internal dispositions and relational dynamics involves risk-taking and uncertainty, which can in turn result in reward. With this is mind, categories, such as curiosity, exploration, as well as novelty-seeking, may further motivate the enactment of a world that is tailored for action, as engagement with ambiguous sensory information will ultimately produce reward[11]. As stated earlier, however, this not only concerns how precise our "interoceptive (bodily), exteroceptive (external) and proprioceptive (motoric) sensory predictions" (Ondobaka, 2017, p. 1332) may be; rather, the minimization of prediction error also involves our embodied capacity to generate experience through action, thereby fostering the creation of new regularities (see Schmidhuber, 2006). Conversely, stationary situations featuring low levels of uncertainty will likely give rise to less functional organism–world couplings, as curiosity rewards are hindered. It should also be noted that when couplings stabilize, there might always be some perturbatory condition that would make the unfolding interaction lean toward particular action-tendencies, disrupting the optimal balance that was initially created. Constant adjustments and control are thus needed to support and maintain the precarious equilibrium between living beings and their niche, recalibrate predictions, and produce efficient solutions for task-specific and open-ended problems. Such adjustments might be described in terms of actions, emotions, sensorimotor schemas, motivations, as well as (context-specific or general) social adaptations. For example, novel behavioral configurations may be developed and re-adapted to better explore one's peripersonal space and address physiological and psychological needs emerged under new ecological conditions. In the following lines, we explore in more detail how such insights may be relevant to creativity research, with a special focus on the issue of domain-generality and domain-specificity.

[11] Recent work has showed that fluctuations in uncertainty are important aspects of aesthetic appreciation and emotional experience of music (Koelsch, 2014; Daikoku, 2019).

Enacting Creativity

The novel and functional adaptations at the basis of the capacity to establish meaningful couplings with the world allow the living system to achieve a certain goal—ranging from the realization of a stable thermodynamic equilibrium with the environment in unicellular organisms to the participation in artistic events for more complex animals like us. For very basic forms of life, this ongoing bidirectional dependency may only relate to a quest for nutrition and the different adaptations this entails; but for more sophisticated beings, such as humans, needs and motivations span different situations and experiences and may include art and music (van der Schyff and Schiavio, 2017; see also Dissanayake, 1988, 1995; Kaufman, 2020). In both music-specific contexts and general bio-cognitive domains, it is suggested that the tension between operational closure and material openness is overcome when a veil of significance is casted upon the environment: this allows living systems to anticipate or address perturbations and take care of and restore their internal metabolic balance as well as their state of equilibrium with their ecology. By doing so, they *enact* their identity, thereby combining local (endogenous) and global (world-involving) contingencies into a newly structured unity. In the following quote, jazz improvisation is taken as an example to describe such bio-cognitive dynamics:

> "The organism's environment is a world of elements that matter to the organism, as assisting or threatening the latter's self-maintenance. So the environment is not a neutral, exterior world but a world already interpreted as an array of self-generated significances. It is perhaps not too far a stretch to say that the continual unfolding of the process of an organism's meaning-making encounter with its environment is like an improvising jazz musician generating musical responses that make sense in the context of her fellow players' (and her own) previous musical 'moves'"
> (Torrance and Schumann, 2019).

Here, the environment is not conceptualized as a pre-given structure "out there" displaying fixed properties and regularities that can be objectively assessed. Rather, it is first and foremost understood as an ongoing network of organism-specific relationships with significance, value, and affordative opportunities that differ across domains and contexts. In other words, "the environment is not a structure imposed on living beings from outside but is in fact a creation of those beings. The environment is not an autonomous process but a reflection of the biology of the species" (Lewontin, 1983, p. 99). Through the enactment of their unique perspectives, agents become meaning-makers who dynamically co-evolve with the world they inhabit. In musical contexts, the environment affords more than changing extant behaviors or regulating metabolic functions: the creation of a musical niche *via* acts of musicking, as we saw, includes online and offline forms of social experience developed through face-to-face situations, or through explicitly imaginative or "felt" dynamics. It is within this adaptive interplay that a concerned, musical perspective is brought forth into the world:

> "traditionally, music composition and performance, have been understood as a realization of preconceived musical structures that through the perceptual and cognitive processes of replication or invention are presented either in real time (as performance) or over an extended period of time (as composition). Yet the nature of musical creativity may suggest further emotional and musical representations of specific, freely associated experiences constructed by the composer or performer. [. . .] Thus, musical creativity, can be best defined as a form of self-realization—a discovery and manifestation of the existence of an authentic self" (Nagy, 2017, p. 73).

This "authentic self," we suggest, escapes individualistic descriptions as it involves both singular and plural dynamics (see Kyselo, 2014 for an accurate analysis of the "enactive self," which emphasizes the role of social interaction). These dynamics are constructed through forms of direct interactions (as when making music together), or through other world-involving engagements (e.g., the constructed norms and conventions to which musicians playing alone intuitively adapt to and transform). But because needs and goals must also reflect the operational closure of the system, the individual components involved in establishing and maintaining the described organism–environment loops are not dissolved; they are enacted in a recursive cycle of skillful adaptations, showing once again how "the boundaries that distinguish self from other, instead of being fixed and hard won, are under constant renegotiation" (Valencia and Froese, 2020).

This insight prompts us to re-assess the polarization between domain-generality and domain-specificity that often frames research and theory in the field of creativity. Creative thoughts and actions that are relevant to a given domain, we suggest, rely on a more general tendency of living systems: the capacity to establish meaningful, novel, and functional relationships with the world they co-evolve with. Accordingly, while different creative artifacts may be produced in response to specific demands, the processes underlying creative production reflect a common bio-cognitive core. But since the working of the latter depends on a continuous interaction between living systems (with their own perspectives, identities, experiences, needs, etc.), and their milieux, it exhibits a self-organized variability that can be hardly articulated in more general terms. In other words, we argue that creative effort entails a range of uniquely developed, specific adaptations, which continuously transform the couplings between an organism and its niche. As these couplings are subject to never-ending feed-back and feed-forward loops involving local and global dynamics, their states are always shifting and transitory. We thus maintain that empirical approaches and theoretical insights that posit a strong separation between domain-specificity and domain-generality may not be enough to capture the wide spectrum of situated activities involved in creative cognition. Instead, we propose that an understanding of creativity as a skillful organism–world adaptation offers a way forward, allowing scholars to better assess the continuous interplay of micro- and macro-scale factors in creative effort. For example, one might examine how broader social, cultural, and ecological dynamics contribute to rapid modifications of creative choices in a given context, and how differences in specific creative activities across domains may affect in real-time more general organism–world couplings (e.g., emotional regulation, social cognition, etc.). Notably, this focus on skillful adaptation allows us to refer to creativity not as a quality that one has or not, but rather as a mode of engagement with the world that one continuously cultivates and brings into the daylight of experience through situated action.

Before concluding, we should note that insights from enactive cognitive science have inspired the development of computational models of creativity in AI (Froese and Ziemke, 2009; Guckelsberger et al., 2017), as well as analyses that focus on the continuity between mindfulness, skilled proficiency, skill acquisition, and the creative activity of improvisers and musical learners (e.g., Schiavio and van der Schyff, 2018; van der Schyff et al., 2018; Torrance and Schumann, 2019). An understanding of musical creativity as adaptation has been also proposed by Reybrouck (2006), who draws a fascinating parallel between the process of dealing with music (described as a skillful form of coping with the sonic world) and epistemic control systems. The latter, in cybernetics, denotes any adaptive device that displays a closed operating loop allowing a constant adjustment to external disturbances. The individual (or the "music user," in his terms) is thus seen by Reybrouck as an adaptive device able to modify its relations with the world by evaluating perceptual primitives and acting upon them consistently. This would reduce external perturbations and induce novel compensatory strategies in the user (i) to alter and expand its perceptual repertoire and (ii) to actively manipulate the world and produce novel musical artifacts. The idea that creativity emerges in the flexible interplay between evaluating and controlling the environment resonates well with the perspective outlined in this paper and aligns with recent views in ecological dynamics that conceive of creativity as a function of the organism–world perceptual attunement (e.g., Araújo et al., 2017; Kimmel, 2017, 2019). This also echoes the description of *creative ecology* offered by Howkins, who states that "creativity is [. . .] a rich mix of ecological factors, primarily diversity, change, learning, and adaptation. It exists only where the ecology permits and it flourishes through adaptive efficiency" (quoted in Barrett, 2012, p. 213). These accounts are particularly well suited to address the motor productivity that characterizes most joint practices (e.g., dance, team-sports, collaborative music-making, etc.; see Gruber, 1989; Hristovski et al., 2011, 2012), emphasizing once again how patterns of adaptive engagement can dynamically transform the experience of the here-and-now and produce variabilities that emerge in longer time-scales.

CONCLUSION AND FUTURE DIRECTIONS

During an interview[12] broadcasted in 1969, Italian composer and conductor Bruno Maderna was asked whether he would conceive of music as an intellectual operation or as a praxis guided by more primordial (e.g., emotional) needs. His answer was that music in general (and musical theater in particular) is best understood as a "social fact," a "necessity," and "a mirror of the relationship between society and the individual." Similar views of music and musical practices have been explored in various ways by scholars working in the context of ethnomusicology and social sciences (e.g., Turino, 2008), music education (e.g., van der Schyff et al., 2016), and evolutionary musicology (e.g., Cross, 2001). Moving from these insights, in this paper, we have argued that creative cognition (in music and beyond) may be understood as an adaptive phenomenon that originates in a primordial, and necessary, sense-making activity—a bio-cognitive inclination to create, transform, and maintain viable relationships with the world. As we saw, this perspective helps mitigate two dichotomies that often drive research and theory in the field: that between individuality and collectivity and that between domain-generality and domain-specificity.

With regard to the former dichotomy, we have discussed how composers and performers often establish meaningful musical connections with others during moments of online and offline interactions, that is, even in cases where the social "other" is physically absent. As Small put it, "any 'artistic' performance, if one examines it with attention, will show itself to involve more than the art which is ostensibly occupied" (Small, 1998, p. 109). And this "more" might be accounted for by considering the interpersonal and cultural contingencies that variously take part in solo musical activity. Accordingly, we have discussed a variety of cases of creative solitary musicking and explored their hidden "plural" and adaptive components. Our examples included (sometimes overlapping) experiences of music composition and performance, ranging from explicitly collaborative activities to the construction of a virtual presence of other performers, composers, or audience members. Are these cases of individual or collective creativity? At the end, the two prove inseparable because aspects that pertain to the most intimate sphere of our individuality (agency, volitions, proclivities, emotions, etc.) are ultimately co-constituted by exogenous factors, and it is in this organism–world co-evolution that creative thinking and doing flourish (see also van der Schyff and Schiavio, in press).

To address the second dichotomy (i.e., domain-general vs. domain-specific creativity), we moved to another scholarly domain, that of enactive cognitive science. By exploring the core tenets of this approach, we have discussed how mental life (and not only creative cognition) can be conceived of as a process whereby agents actively shape and at the same time adapt to the environment in which they are situated. This, as we saw, gives rise to open-ended adjustments in thought and action, allowing agents to creatively (re-)establish, assemble, and decompose different organism–world relationships. We say *creatively*, because these relationships exhibit two properties–*novelty* and *functionality*–that are defining of creative activity and that many scholars would deem creative. Indeed, for such relationships to be "successful," they must continuously renew themselves without moving too far from the contextual landscape from which they originate. To better account for this overlap between creative cognition and mental life, in which individual and ecological factors are constantly negotiated to produce meaningful organism–world couplings, we have reframed the issue of domain-specificity and domain-generality in different terms. That is, rather than understanding domain-generality and domain-specificity as contrasting views that inform empirical practice and theory in one way or another, we have laid down the basis of a conceptual framework that sees creativity as a process of *skillful adaptation*. Here, general principles pertaining to the bio-cognitive organization of living systems (i.e., the capacity to form novel and functional relationships with the world) and specificities of each individual agent (i.e., their unique identity) are thought to be systematically combined in the creative act.

The recognition of a continuous integration of individual, collective, domain-general, and domain-specific creative factors that emerges from our hybrid account can open up fascinating possibilities for future experimental and theoretical work, helping formulate precise empirical questions and fostering interdisciplinary analyses. For an example, we may consider how, in order to produce various compensatory actions to keep their musicking "alive" and pulsating, musicians often decenter their agency, producing patterns of reciprocal exchanges that stabilize and destabilize their activity on the spot (see Ryan and Schiavio, 2019). Here, openings and constraints functional to creative activity are shared between individuals, groups, and ecological variabilities, suggesting that each performer must always negotiate singular and plural dynamics and continuously (re-)generate a range of novel couplings with his or her niche. These couplings, as we have argued, not only involve immediate interactions with co-performers and audience (e.g., to monitor the functionality of precise contextual online adaptations) but also extend to include larger social dynamics (e.g., to situate their musicking into an appropriate context). To better capture this point, we may use the following quote from Orth et al. (2017), with an important addition (in italic):

> "actions are considered as emergent in the temporary couplings formed among the individual and the environment [...]. Importantly, these couplings are not uniquely determined by the individual's characteristics, but in unity with environmental and task constraints. These constraints define the space within which the movement system can act, placing boundaries on the movement solutions available [...]. From this perspective, creative motor actions are as much a function of the individual, as the task and [*the broader cultural, social, and historical*] environment"
>
> (Orth et al., 2017).

In musical terms, creativity here would concern how musicians might intentionally "play" with the continuous integration of such local and global dynamics, making each

[12]The entire interview can be watched at https://www.youtube.com/watch?v=5AxNcusxShQ.

performance unique by fluidly crisscrossing the boundaries between control, risk-taking, contextuality, and spontaneity (see also Berkowitz, 2010; Schiavio and Kimmel, under review; Wopereis et al., 2013). This could help performers generate convincing outcomes that are at the same time original and stylistically coherent, by navigating the range of vicissitudes and adaptations (e.g., emotion, proclivity, empathy, etc.) that shape their coupling with the world in the (precarious, uncertain) here-and-now of creative effort.

Such insights may also be relevant for the neuroscientific community when they can contribute to develop precise research questions and testable hypotheses. An example involves the role played by the sense of agency in creative performance. A recent study by Beyer et al. (2018) demonstrates that participants engaged in social trials (i.e., where decisions to act or not to act depend on another individual) exhibit increased activation of the bilateral temporo-parietal junction (TPJ), precuneus, and middle frontal gyrus when compared with non-social situations. In musical contexts, it has been shown that TPJ activity normally decreases when experts improvise music, whereas it does not change when novices perform the same task (Berkowitz and Ansari, 2010). This suggests that while TPJ may be "naturally" involved in the creation of novel musical outcomes, experts may have inhibited its activation through years of training, as they have been voluntarily engaging with processes involving more self-focused attention. However, while TPJ is modulated by social contexts, it is not affected by the sense of agency. The activity of the precuneus (as demonstrated in the same study by Beyer et al., 2018) tends instead to increase in social conditions and positively correlates with decreased sense of agency. Because our analysis suggests that solo creative activities involve a good deal of intersubjectivity, and because contexts featuring the presence of others are often associated with a reduction in the feeling of being in control of our own actions (see e.g., Sidarus et al., 2020), we would expect that drops in an individual's sense of agency can be observed in subjects performing a creative task by themselves. And as decreased sense of agency is also correlated to the activation of the precuneus in the brain, the prediction can be made that particularly significant moments of creativity (e.g., achieved during solo music improvisation) would involve systematic associations between drops in the sense of agency (e.g., reported verbally) and increased activity of the precuneus (e.g., revealed by fMRI). We have already considered qualitative insights that point to this direction, with verbal descriptions offered by novice and expert musicians highlighting feelings of shared corporeality (see again the "Performing Music" section). It would be thus very interesting to see whether the possible empirical scenario we have outlined would give rise to such results in a sample of both experts and novices. The same experimental setting could also be extended to include and compare other (i.e., non-musical) domains, as the activity of the precuneus has been already positively associated with divergent thinking more generally (see e.g., Benedek et al., 2014b; Jauk et al., 2015).

This last example illustrates well how the recognition of a profound overlap between individuality and collectivity, as found in musical contexts, may stimulate the development of conceptual and experimental tools in other areas. This could help us better navigate the differences between the various dimensions of musical and non-musical creativities, observe in more detail their singular and social components, and describe with increased accuracy the network of adaptations and adjustments at the basis of creative effort, looking beyond existing dichotomies. In conclusion, we hope that researchers investigating the psychology and the neuroscience of creativity, the working of the musical mind, and enactive cognition, could join forces to further develop the insights presented here, providing empirical validations of specific claims and offering novel theoretical resources for research and theory.

DATA AVAILABILITY STATEMENT

No experimental data was generated for the present article.

AUTHOR CONTRIBUTIONS

AS and MB co-wrote and co-edited the manuscript. They have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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REFERENCES

Abraham, A. (2018). *The Neuroscience of Creativity*. Cambridge: Cambridge University Press.

Agnoli, S., Mastria, S., Kirsch, C., and Corazza, G. E. (2019). Creativity in the advertisement domain: the role of experience on creative achievement. *Front. Psychol.* 10:1899. doi: 10.3389/fpsyg.2019.01899

Agnoli, S., Zanon, M., Mastria, S., Avenanti, A., and Corazza, G. E. (2020). Predicting response originality through brain activity: an analysis of changes in EEG alpha power during the generation of alternative ideas. *Neuroimage* 207:116385. doi: 10.1016/j.neuroimage.2019.116385

Amabile, T. M. (1982). Social psychology of creativity: a consensual assessment technique. *J. Personal. Soc. Psychol.* 43, 997–1013. doi: 10.1037/0022-3514.43.5.997

Amabile, T. M. (1983). The social psychology of creativity: a componential conceptualization. *J. Personal. Soc. Psychol.* 45, 357–377. doi: 10.1037/0022-3514.45.2.357

Amabile, T. M. (1985). Motivation and creativity: effects of motivational orientation on creative writers. *J. Pers. Soc. Psychol.* 48, 393–399. doi: 10.1037/0022-3514.48.2.393

Amabile, T. M. (1996). *Creativity in Context*. Boulder: Westview Press.

Amabile, T. M., and Pratt, M. G. (2016). The dynamic componential model of creativity and innovation in organizations: making progress, making meaning. *Res. Organ. Behav.* 36, 157–183. doi: 10.1016/j.riob.2016.10.001

Andrews-Hanna, J. R., Reidler, J. S., Sepulcre, J., Poulin, R., and Buckner, R. L. (2010). Functional-anatomic fractionation of the brain's default network. *Neuron* 65, 550–562. doi: 10.1016/j.neuron.2010.02.005

Andrews-Hanna, J. R., Smallwood, J., and Spreng, R. N. (2014). The default network and self-generated thought: component processes, dynamic control, and clinical relevance. *Ann. N.Y. Acad. Sci.* 1316, 29–52. doi: 10.1111/nyas.12360

Annerer-Walcher, S., Körner, C., and Benedek, M. (2018). Eye behavior does not adapt to expected visual distraction during internally directed cognition. *PLoS One* 13:e0204963. doi: 10.1371/journal.pone.0204963

Apps, M. A., Rushworth, M. F., and Chang, S. W. (2016). The anterior cingulate gyrus and social cognition: tracking the motivation of others. *Neuron* 90, 692–707. doi: 10.1016/j.neuron.2016.04.018

Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., and Davids, K. (2017). Ecological cognition: Expert decision-making behaviour in sport. *Int. Rev. Sport Exerc. Psychol.* 12, 1-25. doi: 10.1080/1750984X.2017.1349826

Badino, L., D'Ausilio, A., Glowinski, D., Camurri, A., and Fadiga, L. (2014). Sensorimotor communication in professional quartets. *Neuropsychologia* 55, 98–104. doi: 10.1016/j.neuropsychologia.2013.11.012

Baer, J. (2012). Domain specificity and the limits of creativity theory. *J. Creat. Behav.* 46, 16–29. doi: 10.1002/jocb.002

Baer, J. (2015). The importance of domain-specific expertise in creativity. *J. Gift. Educ.* 37, 165–178. doi: 10.1080/02783193.2015.1047480

Baggs, E., and Chemero, A. (2018). Radical embodiment in two directions. *Synthese* doi: 10.1007/s11229-018-02020-9

Bailey, D. (1993). *Improvisation: Its Nature and Practice in Music*. Cambridge, MA: Da Capo Press.

Balietti, S., Mäs, M., and Helbing, D. (2015). On disciplinary fragmentation and scientific progress. *PLoS One* 10:e0118747. doi: 10.1371/journal.pone.0118747

Barbot, B., Hass, R. W., and Reiter-Palmon, R. (2019). Creativity assessment in psychological research: (Re)setting the standards. *Psychol. Aesthet. Creat. Arts* 13, 233–240. doi: 10.1037/aca0000233

Barbot, B., and Tinio, P. P. (2015). Where is the "g" in creativity? A specialization-differentiation hypothesis. *Front. Hum. Neurosci.* 8:1041. doi: 10.3389/fnhum.2014.01041

Barrett, M. S. (2012). "Troubling the creative imaginary: Some possibilities of ecological thinking for music and learning," in *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance, and Perception*, eds D. J. Hargreaves, D. Miell, and R. A. R. MacDonald (Oxford: Oxford University Press), 206–219.

Bashwiner, D. (2018). "The neuroscience of musical creativity," in *The Cambridge Handbook of the Neuroscience of Creativity*, eds R. E. Jung and O. Vartanian (Cambridge: Cambridge University Press), 495–516. doi: 10.1017/9781316556238.029

Bashwiner, D., Wertz, C. J., Flores, R. A., and Jung, R. E. (2016). Musical creativity "revealed" in brain structure: interplay between motor, default mode, and limbic networks. *Sci Rep.* 6, 20482. doi: 10.1038/srep20482

Beaty, R. E. (2015). The neuroscience of musical improvisation. *Neurosci. Biobehav. Rev.* 51, 108–117. doi: 10.1016/j.neubiorev.2015.01.004

Beaty, R. E., Benedek, M., Kaufman, S. B., and Silvia, P. J. (2015). Default and executive network coupling supports creative idea production. *Sci. Rep.* 5, 1–14.

Beaty, R. E., Benedek, M., Silvia, P. J., and Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends Cogn. Sci.* 20, 87–95. doi: 10.1016/j.tics.2015.10.004

Beaty, R. E., Chen, Q., Christensen, A. P., Kenett, Y. N., Silvia, P. J., Benedek, M., et al. (2020). Default network contributions to episodic and semantic processing during divergent creative thinking: a representational similarity analysis. *Neuroimage* 209:116499. doi: 10.1016/j.neuroimage.2019.116499

Beaty, R. E., Kenett, Y. N., Christensen, A. P., Rosenberg, M. D., Benedek, M., Chen, Q., et al. (2018a). Robust prediction of individual creative ability from brain functional connectivity. *Proc. Natl. Acad. Sci. U.S.A.* 115, 1087–1092. doi: 10.1073/pnas.1713532115

Beaty, R. E., Seli, P., and Schacter, D. L. (2019). Network neuroscience of creative cognition: mapping cognitive mechanisms and individual differences in the creative brain. *Curr. Opin. Behav. Sci.* 27, 22–30. doi: 10.1016/j.cobeha.2018.08.013

Beaty, R. E., Smeekens, B. A., Silvia, P. J., Hodges, D. A., and Kane, M. J. (2013). A first look at the role of domain-general cognitive and creative abilities in jazz improvisation. *Psychomusicology* 23, 262–268. doi: 10.1037/a0034968

Beaty, R. E., Thakral, P. P., Madore, K. P., Benedek, M., and Schacter, D. L. (2018b). Core network contributions to remembering the past, imagining the future, and thinking creatively. *J. Cogn. Neurosci.* 30, 1939–1951. doi: 10.1162/jocn_a_01327

Behrens, T. E. J., Hunt, L. T., and Rushworth, M. F. S. (2009). The computation of social behavior. *Science* 324, 1160–1164. doi: 10.1126/science.1169694

Benedek, M. (2018). "Internally directed attention in creative cognition," in *The Cambridge Handbook of the Neuroscience of Creativity*, eds R. E. Jung and O. Vartanian (Cambridge: Cambridge University Press), 180–194. doi: 10.1017/9781316556238.011

Benedek, M., Borovnjak, B., Neubauer, A. C., and Kruse-Weber, S. (2014a). Creativity and personality in classical, jazz and folk musicians. *Personal. Individ. Differ.* 63, 117–121. doi: 10.1016/j.paid.2014.01.064

Benedek, M., Bruckdorfer, R., and Jauk, E. (2020a). Motives for creativity: exploring the what and why of everyday creativity. *J. Creat. Behav.* 54, 610–625. doi: 10.1002/jocb.396

Benedek, M., Christensen, A. P., Fink, A., and Beaty, R. E. (2019). Creativity assessment in neuroscience research. *Psychol. Aesthet. Creat. Arts* 13, 218–226. doi: 10.1037/aca0000215

Benedek, M., and Fink, A. (2019). Toward a neurocognitive framework of creative cognition: the role of memory, attention, and cognitive control. *Curr. Opin. Behav. Sci.* 27, 116–122. doi: 10.1016/j.cobeha.2018.11.002

Benedek, M., and Jauk, E. (2014). Creativity: lost in simplification? *Creat. Theor. Res.-Appl.* 1, 213–219. doi: 10.15290/ctra.2014.01.02.06

Benedek, M., and Jauk, E. (2018). "Spontaneous and controlled processes in creative cognition," in *The Oxford Handbook of Spontaneous Thought: Mind-Wandering, Creativity, Dreaming, and Clinical Conditions*, eds K. C. R. Fox and K. Christoff (Oxford: Oxford University Press).

Benedek, M., and Jauk, E. (2019). "Creativity and cognitive control," in *Cambridge Handbook of Creativity*, eds J. Kaufman and R. Sternberg (Cambridge: Cambridge University Press), 200–223. doi: 10.1017/9781316979839.012

Benedek, M., Jauk, E., Beaty, R. E., Fink, A., Koschutnig, K., and Neubauer, A. C. (2016). Brain mechanisms associated with internally directed attention and self-generated thought. *Sci. Rep.* 6:22959. doi: 10.1038/srep22959

Benedek, M., Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., et al. (2014b). To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *Neuroimage* 88, 125–133. doi: 10.1016/j.neuroimage.2013.11.02

Benedek, M., Jauk, E., Kerschenbauer, K., Anderwald, R., and Grond, L. (2017b). Creating art: An experience sampling study in the domain of moving image art. *Psychol. Aesthet. Creat. Arts* 11, 325–334. doi: 10.1037/aca0000102

Benedek, M., Jurisch, J., Koschutnig, K., Fink, A., and Beaty, R. (2020b). Elements of creative thought: investigating the cognitive and neural correlates of association and bi-association processes. *Neuroimage* 210:116586. doi: 10.1016/j.neuroimage.2020.116586

Benedek, M., Kenett, Y., Umdasch, K., Anaki, D., Faust, M., and Neubauer, A. (2017a). How semantic memory structure and intelligence contribute to creative thought: a network science approach. *Think. Reason.* 23, 158–183. doi: 10.1080/13546783.2016.1278034

Benedek, M., Schickel, R. J., Jauk, E., Fink, A., and Neubauer, A. C. (2014). Alpha power increases in right parietal cortex reflects focused internal attention. *Neuropsychologia* 56, 393–400. doi: 10.1016/j.neuropsychologia.2014.02.010

Benedek, M., Schües, T., Beaty, R. E., Jauk, E., Koschutnig, K., Fink, A., et al. (2018). To create or to recall original ideas: brain processes associated with the imagination of novel object uses. *Cortex* 99, 93–102. doi: 10.1016/j.cortex.2017.10.024

Bengtsson, S. L., Csíkszentmihályi, M., and Ullén, F. (2007). Cortical regions involved in the generation of musical structures during improvisation in pianists. *J. Cogn. Neurosci.* 19, 830–842. doi: 10.1162/jocn.2007.19.5.830

Bennett, J. (2012). "Constraint, collaboration and creativity in popular songwriting teams," in *The Act of Musical Composition: Studies in the Creative Process*, ed. D. Collins (Farnham: Ashgate), 139–169.

Berio, L. (1981). *Intervista Sulla Musica*. Bari: Laterza.

Berkowitz, A. L. (2010). *The Improvising Mind: Cognition and Creativity in the Musical Moment*. Oxford: Oxford University Press.

Berkowitz, A. L., and Ansari, D. (2008). Generation of novel motor sequences: the neural correlates of musical improvisation. *Neuroimage* 41, 535–543. doi: 10.1016/j.neuroimage.2008.02.028

Berkowitz, A. L., and Ansari, D. (2010). Expertise-related deactivation of the right temporoparietal junction during musical improvisation. *Neuroimage* 49, 712–719.

Berliner, P. (1994). *Thinking in Jazz: The Infinite Art of Improvisation*. Chicago, IL: University of Chicago Press.

Beyer, F., Sidarus, N., Fleming, S., and Haggard, P. (2018). Losing control in social situations: how the presence of others affects neural processes related to sense of agency. *eNeuro* 5:ENEURO.0336-17.2018. doi: 10.1523/ENEURO.0336-17.2018

Biasutti, M. (2015). Creativity in virtual spaces: communication modes employed during collaborative online music composition. *Think. Skills Creat.* 17, 117–129. doi: 10.1016/j.tsc.2015.06.002

Biasutti, M. (2018). Strategies adopted during collaborative online music composition. *Int. J. Music Educ.* 36, 473–490. doi: 10.1177/0255761417741520

Biasutti, M., Concina, E., Wasley, D., and Williamon, A. (2016). Music regulators in two string quartets: a comparison of communicative behaviors between low- and high-stress performance conditions. *Front. Psychol.* 7:1229. doi: 10.3389/fpsyg.2016.01229

Bisesi, E., Friberg, A., and Parncutt, R. (2019). A computational model of immanent accent salience in tonal music. *Front. Psychol.* 10:317. doi: 10.3389/fpsyg.2019.00317

Bishop, L. (2018). Collaborative musical creativity: how ensembles coordinate spontaneity. *Front. Psychol.* 9:1285. doi: 10.3389/fpsyg.2018.01285

Bishop, L., Bailes, F., and Dean, R. T. (2013). Musical imagery and the planning of dynamics and articulation during performance. *Music Percept.* 31, 97–116. doi: 10.1525/mp.2013.31.2.97

Bishop, L., and Goebl, W. (2015). When they listen and when they watch: Pianist's use of nonverbal audio and visual cues during duet performance. *Music. Sci.* 19, 84–110. doi: 10.1177/1029864915570355

Bishop, L., and Goebl, W. (2018). Beating time: how ensemble musician's cueing gestures communicate beat position and tempo. *Psychol. Music* 46, 84–106. doi: 10.1177/0305735617702971

Boden, M. (1998). What is creativity?" in *Creativity in Human Evolution and Prehistory* ed. S. Mithen (Abingdon: Routledge), 15–43.

Boden, M. A. (2004). *The Creative Mind: Myths and Mechanisms*. Hove: Psychology Press.

Brummelman, E., Thomaes, S., Orobio de Castro, B., Overbeek, G., and Bushman, B. J. (2014). "That's not just beautiful—that's incredibly beautiful!": the adverse impact of inflated praise on children with low self-esteem. *Psychol. Sci.* 25, 728–735. doi: 10.1177/0956797613514251

Burnard, P. (2006). "Understanding children's meaning-making as composers," in *Musical Creativity: Multidisciplinary Research in Theory and Practice*, eds I. Deliège and G. Wiggins (New York, NY: Psychology Press), 111–133.

Burnard, P. (2012). *Musical Creativities in Practice*. Oxford: Oxford University Press.

Byron, K., and Khazanchi, S. (2012). Rewards and creative performance: a meta-analytic test of theoretically derived hypotheses. *Psychol. Bull.* 138, 809–830. doi: 10.1037/a0027652

Cappuccio, M., and Froese, T. (2014). "Introduction to making sense of non-sense," in *Enactive Cognition at the Edge of Sense-Making: Making Sense of Non-Sense*, eds M. Cappuccio and T. Froese (London: Palgrave Macmillan), 4–38.

Carson, S., Peterson, J. B., and Higgins, D. M. (2005). Reliability, validity, and factor structure of the creative achievement questionnaire. *Creat. Res. J.* 17, 37–50. doi: 10.1207/s15326934crj1701_4

Chemero, A. (2009). *Radical Embodied Cognitive Science*. Cambridge, MA: MIT Press.

Christoff, K., Irving, Z. C., Fox, K. C., Spreng, R. N., and Andrews-Hanna, J. R. (2016). Mind-wandering as spontaneous thought: a dynamic framework. *Nat. Rev. Neurosci.* 17, 718–731. doi: 10.1038/nrn.2016.113

Chrysikou, E. G. (2018). "The costs and benefits of cognitive control for creativity," in *The Cambridge Handbook of the Neuroscience of Creativity*, eds R. E. Jung and O. Vartanian (Cambridge: Cambridge University Press), 299–317. doi: 10.1017/9781316556238.018

Clark, A. (2016). *Surfing Uncertainty: Prediction, Action, and the Embodied Mind*. Oxford: Oxford University Press.

Clarke, E. (2002). "Understanding the psychology of performance," in *Musical Performance: A Guide to Understanding*, ed. J. Rink (Cambridge: Cambridge University Press), 59–72. doi: 10.1017/CBO9780511811739.005

Clarke, E., and Doffman, M. (eds) (2017). *Distributed creativity: Collaboration and improvisation in contemporary Music*. Oxford: Oxford University Press.

Clarke, E., Doffman, M., and Lim, L. (2013). Distributed creativity and ecological dynamics: a case study of Liza Lim's 'Tongue of the Invisible'. *Music Lett.* 94, 628–663. doi: 10.1093/ml/gct118

Clarke, E., Doffman, M., and Timmers, R. (2016). Creativity, collaboration and development in Jeremy Thurlow's Ouija for Peter Sheppard Skaerved. *J. Royal Music. Assoc.* 141, 113–165. doi: 10.1080/02690403.2016.1151240

Cook, N. (2001). Between process and product: music and/as performance. *Music Theory Online* 7. https://mtosmt.org/issues/mto.01.7.2/mto.01.7.2.cook.html

Cook, N. (2006). "Playing God: Creativity, analysis, and aesthetic inclusion," in *Musical Creativity: Multidisciplinary Research in Theory and practice*, eds I. Deliège and G. Wiggins (Hove: Psychology Press), 9–24.

Cook, N. (2013). *Beyond the Score: Music as Performance*. Oxford: Oxford University Press.

Cook, N. (2018). *Music As Creative Practice*. Oxford: Oxford University Press.

Cross, I. (2001). Music, cognition, culture, and evolution. *Ann. N.Y. Acad. Sci.* 930, 28–42. doi: 10.1111/j.1749-6632.2001.tb05723.x

Csikszentmihalyi, M. (1988). "The dangers of originality: creativity and the artistic process," in *Psychoanalytic Perspectives on Art*, ed. M. Gedo (Berkeley: Analytic Press).

Csikszentmihalyi, M. (1997). *Flow and the Psychology of Discovery and Invention*. New York, NY: Harper Perennial.

Cuffari, E. C., Di Paolo, E., and De Jaegher, H. (2015). From participatory sense-making to language: there and back again. *Phenomenol. Cogn. Sci.* 14, 1089–1125. doi: 10.1007/s11097-014-9404-9

Daikoku, T. (2019). Implicit knowledge and the uncertainty on musical creativity fluctuate over a composer's lifetime. *Front. Comput. Neurosci.* 13:27. doi: 10.3389/fncom.2019.00027

Davidson, J. (2002). "Communicating with the body in performance," in *Musical Performance: A Guide to Understanding*, ed. J. Rink (Cambridge: Cambridge University Press), 144–152. doi: 10.1017/CBO9780511811739.011

Davidson, J. W., and Good, J. M. M. (2002). Social and musical co-ordination between members of a string quartet: an exploratory study. *Psychol. Music* 30, 186–201. doi: 10.1177/0305735602302005

De Jaegher, H., Peräkylä, A., and Stevanovic, M. (2016). The co-creation of meaningful action: bridging enaction and interactional sociology. *Philos. Trans. Royal Soc. Lond. Ser. B Biol. Sci.* 371:20150378. doi: 10.1098/rstb.2015.0378

De Jesus, P. (2018). Thinking through enactive agency: sense-making, bio-semiosis and the ontologies of organismic worlds. *Phenom. Cogn. Sci.* 17, 861–887. doi: 10.1007/s11097-018-9562-2

de Manzano, Ö, and Ullén, F. (2012). Activation and connectivity patterns of the presupplementary and dorsal premotor areas during free improvisation of melodies and rhythms. *Neuroimage* 63, 272–280. doi: 10.1016/j.neuroimage.2012.06.024

De Rosa, D. M., Smith, C. L., and Hantula, D. A. (2007). The medium matters: mining the long-promised merit of group interaction in creative idea generation tasks in a meta-analysis of the electronic group brainstorming literature. *Comp. Hum. Behav.* 23, 1549–1581. doi: 10.1016/j.chb.2005.07.003

Di Paolo, E. (2005). Autopoiesis, adaptivity, teleology, agency. *Phenom. Cogn. Sci.* 4, 97–125.

Di Paolo, E. (2009). Extended life. *Topoi* 28, 9–21.

Di Paolo, E., Buhrmann, T., and Barandiaran, X. E. (2017). *Sensorimotor Life: An Enactive Proposal*. Oxford: Oxford University Press.

Di Paolo, E., and Thompson, E. (2014). "The enactive approach," in *Routledge Handbooks in Philosophy. The Routledge Handbook of Embodied Cognition*, ed. L. Shapiro (Abingdon: Routledge), 68–78.

Diedrich, J., Benedek, M., Jauk, E., and Neubauer, A. C. (2015). Are creative ideas novel and useful? *Psychol. Aesthet. Creat. Arts* 9, 35–40.

Diedrich, J., Jauk, E., Silvia, P. J., Gredlein, J. M., Neubauer, A. C., and Benedek, M. (2018). Assessment of real-life creativity: the inventory of creative activities and achievements (ICAA). *Psychol. Aesthet. Creat. Arts* 12, 304–316. doi: 10.1037/aca0000137

Diehl, M., and Stroebe, W. (1987). Productivity loss in brainstorming groups: toward the solution of a riddle. *J. Personal. Soc. Psychol.* 53, 497–509. doi: 10.1037/0022-3514.53.3.497

Dietrich, A., and Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychol. Bull.* 136:822. doi: 10.1037/a0019749

Dillon, T. (2006). "Hail to the thief: The appropriation of music in the digital age," in *Consuming Music Together. Computer Supported Cooperative Work*, eds K. O'Hara and B. Brown (New York, NY: Springer).

Dissanayake, E. (1988). *What is Art for?* Seattle: University of Washington Press.

Dissanayake, E. (1995). *Homo Aestheticus: Where Art Comes From and Why*. Seattle: University of Washington Press.

Dobrian, C. (1991). *Thoughts on composition and improvisation*. Unpublished manuscript, Claire Trevor School of the Arts, University of California, Irvine. https://music.arts.uci.edu/dobrian/CD.comp.improv.htm (accessed June 10, 2020).

Doffman, M. (2009). Making it groove! Entrainment, participation and discrepancy in the 'conversation' of a jazz trio. *Lang. History* 52, 130–147. doi: 10.1179/175975309x452012

Doffman, M., and Calvin, J.-P. (2017). "Contemporary music in action: performer-composer collaboration within the conservatoire," in *Distributed Creativity: Collaboration and Improvisation in Contemporary Music*, eds E. Clarke and M. Doffman (Oxford: Oxford University Press), 184–198.

Donin, N., and Traube, C. (2016). Tracking the creative process in music: new issues, new methods. *Musicae Sci.* 20, 283–286. doi: 10.1177/1029864916656995

Duby, M. (2018). Improvisation unfolding: Process, pattern, and prediction. *World Futures* 74, 187–198. doi: 10.1080/02604027.2017.1345249

Dugosh, K. L., and Paulus, P. B. (2005). Cognitive and social comparison processes in brainstorming. *J. Exp. Soc. Psychol.* 41, 313–320. doi: 10.1016/j.jesp.2004.05.009

Dumas, G. (2011). Towards a two-body neuroscience. *Commun. Integr. Biol.* 4, 349–352. doi: 10.4161/cib.4.3.15110

Eysenck, H. J. (1995). *Genius: The Natural History of Creativity*. Cambridge: Cambridge University Press.

Feist, G. J. (1998). A meta-analysis of personality in scientific and artistic creativity. *Pers. Soc. Psychol. Rev.* 2, 290–309. doi: 10.1207/s15327957pspr0204_5

Fink, A., and Benedek, M. (2014). EEG alpha power and creative ideation. *Neurosci. Biobehav. Rev.* 44, 111–123. doi: 10.1016/j.neubiorev.2012.12.002

Fink, A., Benedek, M., Koschutnig, K., Pirker, E., Berger, E., Meister, S., et al. (2015). Training of verbal creativity modulates brain activity in regions associated with language-and memory-related demands. *Hum. Brain Mapp.* 36, 4104–4115. doi: 10.1002/hbm.22901

Fink, A., Graif, B., and Neubauer, A. C. (2009). Brain correlates underlying creative thinking: EEG alpha activity in professional vs. *novice dancers. Neuroimage* 46, 854–862. doi: 10.1016/j.neuroimage.2009.02.036

Folkestad, G. (2012). "Digital tools and discourse in music: The ecology of composition," in *Musical Imaginations*, eds D. J. Hargreaves, D. E. Miell, and R. A. R. MacDonald (Oxford: Oxford University Press), 193–205. doi: 10.1093/acprof:oso/9780199568086.003.0012

Forgeard, M. J. C., and Kaufman, J. C. (2016). Who cares about imagination, creativity, and innovation, and why? A review. *Psychol. Aesthet. Creat. Arts* 10, 250–269. doi: 10.1037/aca0000042

Friston, K. (2010). The free-energy principle: a unified brain theory? *Nat. Rev. Neurosci.* 11, 127–138. doi: 10.1038/nrn2787

Friston, K., Daunizeau, J., Kilner, J., and Kiebel, S. J. (2010). Action and behavior: a free-energy formulation. *Biol. Cybernet.* 102, 227–260. doi: 10.1007/s00422-010-0364-z

Frith, S. (1996). *Performing rites. On the value of popular music*. Oxford: Oxford University Press.

Froese, T., and Di Paolo, E. A. (2011). The enactive approach: theoretical sketches from cell to society. *Pragmat. Cogn*. 19, 1–36. doi: 10.1075/pc.19.1.01fro

Froese, T., and Ziemke, T. (2009). Enactive Artificial Intelligence: Investigating the systemic organization of life and mind. *Journal of Artificial Intelligence* 173, 466–500. doi: 10.1016/j.artint.2008.12.001

Fuchs, T. (2018). *Ecology of the brain: The phenomenology and biology of the embodied mind*. Oxford: Oxford University Press.

Gabrielsson, A. (2001). "Emotions in strong experiences with music," in *Series in affective Science. Music and Emotion: Theory and Research*, eds P. N. Juslin and J. A. Sloboda (Oxford: Oxford University Press), 431–449.

Gallagher, S. (2017). *Enactivist Interventions: Rethinking the Mind*. Oxford: Oxford University Press.

Gergen, K. J. (1994). *Realities and Relationships, Soundings in Social Construction*. Cambridge, MA: Harvard University Press.

Gilhooly, K. J., Fioratou, E., Anthony, S. H., and Wynn, V. (2007). Divergent thinking: strategies and executive involvement in generating novel uses for familiar objects. *Br. J. Psychol.* 98(Pt. 4), 611–625. doi: 10.1111/j.2044-8295.2007.tb00467.x

Gilhooly, K. J., and Murphy, P. (2005). Differentiating insight from non-insight problems. *Think. Reason.* 11, 279–302. doi: 10.1080/13546780442000187

Glăveanu, V. P. (2013). Rewriting the language of creativity: The five A's framework. *Rev. Gen. Psychol.* 17, 69–81. doi: 10.1037/a0029528

Glăveanu, V. P. (2014). *Distributed Creativity*: *Thinking Outside the Box of the Creative individual*. New York, NY: Springer.

Gould van Praag, C., Garfinkel, S., and Sparasci, O. (2017). Mind-wandering and alterations to default mode network connectivity when listening to naturalistic versus artificial sounds. *Sci. Rep.* 7:45273. doi: 10.1038/srep45273

Gruber, H. (1989). "The evolving system approach to creativity," in *Creative People at Work: Twelve Cognitive Case Studies*, eds H. Gruber and D. B. Wallace (Oxford: Oxford University Press).

Guckelsberger, C., Salge, C., and Colton, S. (2017). "Addressing the "why?" in computational creativity: A non-anthropocentric, minimal model of intentional creative agency," in *Proceedings of the 8th International Conference on Computational Creativity (ICCC'17)*, Atlanta,

Guilford, J. P. (1967). *The Nature of Human Intelligence*. New York, NY: McGraw-Hill.

Hari, R., and Kujala, M. V. (2009). Brain basis of human social interaction: from concepts to brain imaging. *Physiol. Rev.* 89, 453–479. doi: 10.1152/physrev.00041.2007

Hickey, M. (1995). *Qualitative and Quantitative Relationships Between Children's Creative Musical Thinking Processes and Products*. Unpublished doctoral dissertation. Evanston, IL: Northwestern University.

Hickey, M. (1997). The computer as a tool in creative music making. *Res. Stud. Music Educ.* 2, 15–24.

Hickey, M. (2000). "The use of consensual assessment in the evaluation of children's music compositions," in *Proceedings from the Sixth International Conference on Music Perception and Cognition*, eds C. Woods, G. Luck, R. Brochard, F. Sneddon, and J. Sloboda (Keele: ICPMC).

Hill, J. (2018). *Becoming Creative: Insights From Musicians in A Diverse World*. Oxford: Oxford University Press.

Hochman, E. Y., Vaidya, A. R., and Fellows, L. K. (2014). Evidence for a role for the dorsal anterior cingulate cortex in disengaging from an incorrect action. *PLoS One* 9:e101126. doi: 10.1371/journal.pone.0101126

Høffding, S., and Satne, G. (2019). Interactive expertise in solo and joint musical performance. *Synthese* 1–19.

Hristovski, R., Davids, K., Araújo, D., and Passos, P. (2011). Constraints-induced emergence of functional novelty in complex neurobiological systems: a basis for creativity in sport. *Nonlinear Dyn. Psychol. Life Sci.* 15, 175–206.

Hristovski, R., Davids, K., Passos, P., and Araújo, D. (2012). Sport performance as a domain of creative problem solving for self-organizing performer-environment systems. *Open Sports Sci. J.* 5, 26–35. doi: 10.2174/1875399x01205010026

Ingold, T., and Hallam, E. (2007). "Creativity and cultural improvisation: an introduction," in *Creativity and cultural improvisation*, eds T. Ingold and E. Hallam (Oxford: Berg Publisher), 1–24. doi: 10.2307/j.ctt18fs9q6.4

Jäncke, L. (2008). Music, memory and emotion. *J. Biol.* 7:21. doi: 10.1186/jbiol82

Jauk, E., Benedek, M., and Neubauer, A. C. (2014). The road to creative achievement: A latent variable model of ability and personality predictors. *Eur. J. Pers.* 28, 95–105. doi: 10.1002/per.1941

Jauk, E., Neubauer, A. C., Dunst, B., Fink, A., and Benedek, M. (2015). Gray matter correlates of creative potential: a latent variable voxel-based morphometry study. *Neuroimage* 111, 312–320. doi: 10.1016/j.neuroimage.2015.02.002

Jensen, O., Bonnefond, M., and VanRullen, R. (2012). An oscillatory mechanism for prioritizing salient unattended stimuli. *Trends Cogn. Sci.* 16, 200–206. doi: 10.1016/j.tics.2012.03.002

Johnson-Laird, P. N. (1988). "Freedom and constraint in creativity," in *The Nature of Creativity*, ed. R. J. Sternberg (Cambridge: Cambridge University Press), 202–219.

Jung, R. E., and Vartanian, O. (eds) (2018). *The Cambridge Handbook of the Neuroscience of Creativity*. Cambridge: Cambridge University Press.

Juslin, P. N. (2019). *Musical Emotions Explained. Unlocking the Secrets of Musical Affect*. Oxford: Oxford University Press.

Karwowski, M., and Kaufman, J. C. (eds) (2017). *The Creative Self: Effect of Beliefs, Self-Efficacy, Mindset, and Identity*. Cambridge, MA: Elsevier Academic Press.

Kaufman, J. C., and Baer, J. (2004). Sure, I'm creative—But not in mathematics! Self-reported creativity in diverse domains. *Emp. Stud. Arts* 22, 143–155. doi: 10.2190/26HQ-VHE8-GTLN-BJJM

Kaufman, J. C., and Beghetto, R. A. (2009). Beyond big and little: the four C model of creativity. *Rev. Gen. Psychol.* 13, 1–12. doi: 10.1037/a0013688

Kaufman, S. B. (2020). *Transcend: The New Science of Self-Actualization*. New York, NY: Penguin Random House.

Kellner, R., and Benedek, M. (2017). The role of creative potential and intelligence for humor production. *Psychol. Aesthet. Creat. Arts* 11, 52–58. doi: 10.1037/aca0000065

Kenett, Y. N., Anaki, D., and Faust, M. (2014). Investigating the structure of semantic networks in low and high creative persons. *Front. Hum. Neurosci.* 8:407. doi: 10.3389/fnhum.2014.00407

Kimmel, M. (2017). "The complexity of skillscapes: Skill sets, synergies, and meta-regulation in joint embodied improvisation," in *Proceedings of the 13th International Conference on Naturalistic Decision Making*, 20-23 June 2017, eds J. Gore and P. Ward (Bath: University of Bath), 102–109.

Kimmel, M. (2019). "A cognitive theory of joint improvisation: The case of Tango Argentino," in *The Oxford Handbook of Improvisation in Dance*, ed. V. L. Midgelow (Oxford: Oxford University Press), 562–592. doi: 10.1093/oxfordhb/9780199396986.013.32

Kimmel, M., Hristova, D., and Kussmaul, K. (2018). Sources of embodied creativity: interactivity and ideation in contact improvisation. *Behav. Sci.* 8:52. doi: 10.3390/bs8060052

Kimmel, M., and Rogler, C. R. (2018). Affordances in interaction: the case of aikido. *Ecol. Psychol.* 30, 195–223. doi: 10.1080/10407413.2017.1409589

Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences* 16, 606–617. doi: 10.1016/j.tics.2012.10.007

Knapp, R. R. (2011). *Tracing the Segovia style: Collaboration and composition in the guitar Sonatinas of Manuel Maria Ponce*. Unpublished DMA Dissertation. The University of Georgia, Athens.

Koelsch, S. (2014). Brain correlates of music-evoked emotions. *Nat. Rev. Neurosci.* 15, 170–180. doi: 10.1038/nrn3666

Kolossa, A., Kopp, B., and Fingscheidt, T. (2015). A computational analysis of the neural bases of Bayesian inference. *Neuroimage* 106, 222–237. doi: 10.1016/j.neuroimage.2014.11.007

Kyselo, M. (2014). The body social: an enactive approach to the self. *Front. Psychol.* 5:986. doi: 10.3389/fpsyg.2014.00986

Leman, M. (2008). *Embodied Music Cognition and Mediation Technology*. Cambridge, MA: MIT Press.

Lewontin, R. (1983). The organism as the subject and object of evolution. *Scientia* 118, 63–82.

Limb, C. J., and Braun, A. R. (2008). Neural substrates of spontaneous musical performance: an fMRI study of jazz improvisation. *PLoS One* 3:e1679. doi: 10.1371/journal.pone.0001679

Liu, S., Erkkinen, M. G., Healey, M. L., Xu, Y., Swett, K. E., Chow, H. M., et al. (2015). Brain activity and connectivity during poetry composition: toward a multidimensional model of the creative process. *Hum. Brain Mapp.* 36, 3351–3372.

Loaiza, J. M. (2016). Musicking, embodiment and the participatory enaction of music: outline and key points. *Conn. Sci.* 28, 410–422. doi: 10.1080/09540091.2016.1236366

Loehr, J. D., Kourtis, D., Vesper, C., Sebanz, N., and Knoblich, G. (2013). Monitoring individual and joint action outcomes in duet music performance. *J. Cogn. Neurosci.* 25, 1049–1061. doi: 10.1162/jocn_a_00388

Lopata, J. A., Nowicki, E. A., and Joanisse, M. F. (2017). Creativity as a distinct trainable mental state: an EEG study of musical improvisation. *Neuropsychologia* 99, 246–258. doi: 10.1016/j.neuropsychologia.2017.03.020

Lu, J., Yang, H., Zhang, X., He, H., Luo, C., and Yao, D. (2015). The brain functional state of music creation: an fMRI study of composers. *Sci. Rep.* 5:12277. doi: 10.1038/srep12277

Lubart, T. I. (2001). Models of the creative process: past, present and future. *Creat. Res. J.* 13, 295–308. doi: 10.1207/s15326934crj1334_07

Luft, C. D. B., Zioga, I., Thompson, N. M., Banissy, M. J., and Bhattacharya, J. (2018). Right temporal alpha oscillations as a neural mechanism for inhibiting obvious associations. *Proc. Natl. Acad. Sci. U.S.A.* 115, E12144–E12152.

Lustenberger, C., Boyle, M. R., Foulser, A. A., Mellin, J. M., and Fröhlich, F. (2015). Functional role of frontal alpha oscillations in creativity. *Cortex* 67, 74–82. doi: 10.1016/j.cortex.2015.03.012

Mado Proverbio, A. (2019). *Le neuroscienze Cognitive Della Musica*. Bologna: Zanichelli.

Madore, K. P., Addis, D. R., and Schacter, D. L. (2015). Creativity and memory: effects of an episodic-specificity induction on divergent thinking. *Psychol. Sci.* 26, 1461–1468. doi: 10.1177/0956797615591863

Malinin, L. H. (2019). How radical is embodied creativity? Implications of 4E approaches for creativity research and teaching. *Front. Psychol.* 10:2372. doi: 10.3389/fpsyg.2019.02372

Matheson, H. E., and Kenett, Y. N. (2020). The role of the motor system in generating creative thoughts. *Neuroimage* 213:116697. doi: 10.1016/j.neuroimage.2020.116697

Maturana, H., and Varela, F. (1980). *Autopoiesis and Cognition: The Realization of the Living*. Kufstein: Reidel.

Mednick, S. A. (1962). The associative basis of the creative process. *Psychol. Rev.* 69, 220–232. doi: 10.1037/h0048850

Montuori, A., and Purser, R. E. (eds) (1999). *Social Creativity*, Vol. 1. Hempstead, NY: Hampton Press.

Montuori, A., and Purser, R. E. (1995). Deconstructing the lone genius myth: Toward a contextual view of creativity. *J. Human. Psychol.* 35, 69–112. doi: 10.1177/00221678950353005

Mueller, J. S., Melwani, S., and Goncalo, J. A. (2012). The bias against creativity: why people desire but reject creative ideas. *Psychol. Sci.* 23, 13–17. doi: 10.1177/0956797611421018

Murray, A. (1998). "Improvisation and the creative process," in *The Jazz Cadence of American Culture*, ed. R. G. O' Meally (New York, NY: Columbia University Press).

Nagy, Z. (2017). *Embodiment of Musical Creativity: The Cognitive and Performative Causality of Musical Composition*. Abingdon: Routledge.

Olivetti Belardinelli, M. (2002). "Beyond global and local theories of musical creativity: looking for specific indicators of mental activity during music processing," in *Musical Creativity: Multidisciplinary Research in Theory and Practice*, eds I. Deliege and G. Wiggins (Hove: Psychology Press), 322–344.

Ondobaka, S. (2017). Andy Clark. surfing uncertainty—prediction, action, and the embodied mind. *Perception* 46, 1331–1333. doi: 10.1177/0301006617714548

Orth, D., van der Kamp, J., Memmert, D., and Savelsbergh, G. J. P. (2017). Creative motor actions as Emerging from movement variability. *Front. Psychol.* 8:1903. doi: 10.3389/fpsyg.2017.01903

Osborn, A. F. (1963). *Applied Imagination: Principles and Procedures of Creative Problem-Solving*. New York, NY: Charles Scribner's Sons.

Parncutt, R. (2003). "Accents and expression in piano performance," in *Perspektiven und Methoden einer Systemischen Musikwissenschaft*, ed. K. W. Niemöller (Bern: Peter Lang AG)163–185.

Pinho, A. L., Ullén, F., Castelo-Branco, M., Fransson, P., and de Manzano, Ö (2015). Addressing a paradox: dual strategies for creative performance in introspective and extrospective networks. *Cereb. Cortex* 26, 3052–3063. doi: 10.1093/cercor/bhv130

Pinsonneault, A., Barki, H., Gallupe, R. B., and Hoppen, N. (1999). Electronic brainstorming: the illusion of productivity. *Inform. Syst. Res.* 10, 110–133. doi: 10.1287/isre.10.2.110

Plucker, J. A. (1999). Is the proof in the pudding? Reanalyses of Torrance's (1958 to present) longitudinal data. *Creat. Res. J.* 12, 103–114. doi: 10.1207/s15326934crj1202_3

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., and Shulman, G. L. (2001). A default mode of brain function. *Proc. Natl. Acad. Sci. U.S.A.* 98, 676–682. doi: 10.1073/pnas.98.2.676

Redcay, E., and Schilbach, L. (2019). Using second-person neuroscience to elucidate the mechanisms of social interaction. *Nat. Rev. Neurosci.* 20, 495–505. doi: 10.1038/s41583-019-0179-4

Reiter-Palmon, R., Forthmann, B., and Barbot, B. (2019). Scoring divergent thinking tests: a review and systematic framework. *Psychol. Aesthet. Creat. Arts* 13, 144–152.

Repp, B. H. (1997). The aesthetic quality of a quantitatively average music performance: two preliminary experiments. *Music Percept.* 14, 419–444. doi: 10.2307/40285732

Reybrouck, M. (2006). "Musical creativity between symbolic modeling and perceptual constraints: The role of adaptive behaviour and epistemic autonomy," in *Musical Creativity: Multidisciplinary Research in Theory and Practice*, eds I. Deliège and G. A. Wiggins (Hove: Psychology Press), 42–59.

Rhodes, M. (1961). An analysis of creativity. *Phi Delta Kappan* 42, 305–310.

Roebroeck, A. (2015). "Granger causality," in *Brain Mapping: An Encyclopedic Reference*, eds P. Thompson and K. Friston (Amsterdam: Elsevier).

Root-Bernstein, R., Allen, L., Beach, L., Bhadula, R., Fast, J., Hosey, C., et al. (2008). Arts foster scientific success: avocations of nobel, national academy, royal society, and sigma Xi members. *J. Psychol. Sci. Technol.* 1, 51–63. doi: 10.1891/1939-7054.1.2.51

Runco, M., and Jaeger, G. (2012). The standard definition of creativity. *Creat. Res. J.* 24, 92–96. doi: 10.1080/10400419.2012.650092

Ryan, K., and Schiavio, A. (2019). Extended musicking, extended mind, extended agency. *Notes on the third wave. New Ideas Psychol.* 55, 8–17. doi: 10.1016/j.newideapsych.2019.03.001

Saris, I. M. J., Penninx, B. W. J. H., and Dinga, R. (2020). Default mode network connectivity and social dysfunction in major depressive disorder. *Sci. Rep.* 10:194. doi: 10.1038/s41598-019-57033-2

Sawyer, R. K. (1992). Improvisational creativity: an analysis of jazz performance. *Creat. Res. J.* 5, 253–263. doi: 10.1080/10400419209534439

Sawyer, R. K. (1999). The emergence of creativity. *Philos. Psychol.* 12, 447–469.

Sawyer, R. K. (2003). *Group Creativity: Music, Theater, Collaboration*. Mahwah: Erlbaum.

Sawyer, R. K. (2006). Group creativity: musical performance and collaboration. *Psychol. Music* 34, 148–165. doi: 10.1177/0305735606061850

Sawyer, R. K., and De Zutter, S. (2009). Distributed creativity: how collective creations emerge from collaboration. *Psychol. Aesthet. Creat. Arts* 3, 81–92. doi: 10.1037/a0013282

Schacter, D. L., Addis, D. R., Hassabis, D., Martin, V. C., Spreng, R. N., and Szpunar, K. K. (2012). The future of memory: remembering, imagining, and the brain. *Neuron* 76, 677–694. doi: 10.1016/j.neuron.2012.11.001

Schiavio and Kimmel (under review). The ecological dynamics of musical creativity and skill acquisition.

Schiavio, A., Moran, N., van der Schyff, D., Biasutti, M., and Parncutt, R. (2020). Processes and experiences of creative cognition in seven Western classical composers. *Music. Sci.* Online first. doi: 10.1177/1029864920943931

Schiavio, A., Ryan, K., Moran, N., van der Schyff, D., and Gallagher, S. (under review). By myself but not alone. agency, creativity, and extended musical historicity.

Schiavio, A., and van der Schyff, D. (2018). 4E music pedagogy and the principles of self-organization. *Behav. Sci.* 8:72. doi: 10.3390/bs8080072

Schiavio, A., van der Schyff, D., Kruse-Weber, S., and Timmers, R. (2017). When the sound becomes the goal. 4E cognition and teleomusicality in early infancy. *Front. Psychol.* 8:1585. doi: 10.3389/fpsyg.2017.01585

Schmidhuber, J. (2006). Developmental robotics, optimal artificial curiosity, creativity, music, and the fine arts. *Conn. Sci.* 18, 173–187. doi: 10.1080/09540090600768658

Schoevers, E. M., Kroesbergen, E. H., and Kattou, M. (2018). Mathematical creativity: a combination of domain-general creative and domain-specific mathematical skills. *J. Creat. Behav.* 54, 242-252. doi: 10.1002/jocb.361

Scott, C. L. (1999). Teachers' biases toward creative children. *Creat. Res. J.* 12, 321–328. doi: 10.1207/s15326934crj1204_10

Shmailov, M. M. (2016). *Intellectual pursuits of Nicolas Rashevsky*. Cham: Springer International Publishing Switzerland.

Sidarus, N., Travers, E., Haggard, P., and Beyer, F. (2020). How social contexts affect cognition: mentalizing interferes with sense of agency during voluntary action. *J. Exp. Soc. Psychol.* 89:103994. doi: 10.1016/j.jesp.2020.103994

Silvia, P. J., Kaufman, J. C., and Pretz, J. E. (2009). Is creativity domain-specific? Latent class models of creative accomplishments and creative self-descriptions. *Psychol. Aesthet. Creat. Arts* 3, 139–148. doi: 10.1037/a0014940

Simonton, D. K. (1988). *Scientific Genius: A Psychology of Science*. Cambridge: Cambridge University Press.

Simonton, D. K. (1999). *Origins of Genius: Darwinian Perspectives on Creativity*. Oxford: Oxford University Press.

Small, C. (1998). *Musicking: The Meanings of Performing and Listening*. Lebanon, NH: University Press of New England.

Sowden, P., Pringle, A., and Gabora, L. (2015). The shifting sands of creative thinking: Connections to dual process theory. *Think. Reason.* 21, 40–60. doi: 10.1080/13546783.2014.885464

Sternberg, R. J. (2009). "Domain-generality versus domain-specificity of creativity," in *Milieus of Creativity: An Interdisciplinary Approach to Spatiality of Creativity*, eds P. Meusburger, J. Funke, and E. Wunder (New York, NY: Springer), 25–38. doi: 10.1007/978-1-4020-9877-2_3

Sternberg, R. J., and Kaufman, J. C. (2010). "Constraints on creativity: Obvious and not so obvious," in *The Cambridge Handbook of Creativity*, eds J. C. Kaufman and R. J. Sternberg (Cambridge: Cambridge University Press), 467–482.

Stevens, C. E. Jr, and Zabelina, D. L. (2019). Creativity comes in waves: an EEG-focused exploration of the creative brain. *Curr. Opin. Behav. Sci.* 27, 154–162. doi: 10.1016/j.cobeha.2019.02.003

Stewart, J., Gapenne, O., and di Paolo, E. A. (eds) (2010). *Enaction: Towards a New Paradigm for Cognitive Science*. Cambridge, MA: MIT Press.

Thompson, E. (2005). Sensorimotor subjectivity and the enactive approach to experience. *Phenomenol. Cogn. Sci.* 4, 407–427. doi: 10.1007/s11097-005-9003-x

Thompson, E. (2007). *Mind in Life: Biology, Phenomenology, and the Sciences of Mind*. Cambridge, MA: Harvard University Press.

Torrance, E. P. (1974). The torrance tests of creative thinking - norms-technical manual research Edition - verbal tests, forms A and B - figural tests, forms A and B. *Person. Press*

Torrance, E. P. (1984). *The Torrance Tests of Creative Thinking streamlined (revised) manual Figural A and B*. Scholastic Testing Services. Bensenville, IL: Scholastic Testing Service Inc.

Torrance, S., and Schumann, F. (2019). The spur of the moment: what jazz improvisation tells cognitive science. *AI Soc* 34, 251–268. doi: 10.1007/s00146-018-0838-4

Turino, T. (2008). *Music As Social Life: The Politics of Participation*. Chicago, IL: University of Chicago Press.

Uddin, L. Q. (2015). Salience processing and insular cortical function and dysfunction. *Nat. Rev. Neurosci.* 16, 55–61. doi: 10.1038/nrn3857

Valencia, A. L., and Froese, T. (2020). What binds us? Inter-brain neural synchronization and its implications for theories of human consciousness. *Neurosci. Conscious.* 1:niaa010. doi: 10.1093/nc/niaa010

Vallee-Tourangeau, F., Steffensen, S. V., Vallee-Tourangeau, G., and Sirota, M. (2016). Insight with hands and things. *Acta Psychol.* 170, 195–205. doi: 10.1016/j.actpsy.2016.08.006

Vallee-Tourangeau, G., and Vallee-Tourangeau, F. (2014). The spatio-temporal dynamics of systemic thinking. *Cybernet. Hum. Knowing* 21, 113–127.

van der Schyff, D. (2015). Music as a manifestation of life: exploring enactivism and the 'eastern perspective' for music education. *Front. Psych.* 6:345. doi: 10.3389/fpsyg.2015.00345

van der Schyff, D. (2019). "Improvisation, Enaction and Self-Assessments," in *The Oxford Handbook of Philosophical and Qualitative Perspectives on Assessment in Music Education*, eds D. Elliott, G. McPherson, and M. Silverman (Oxford: Oxford University Press), 319–346.

van der Schyff, D., and Schiavio, A. (2017). Evolutionary musicology meets embodied cognition. biocultural coevolution and the enactive origins of human musicality. *Front. Neurosci.* 11:519. doi: 10.3389/fnins.2017.00519

van der Schyff, D., and Schiavio, A. (in press). "Musical creativity in performance," in *The Oxford Handbook of Music Performance*, Vol. 1, ed. G. McPherson (Oxford University Press).

van der Schyff, D., Schiavio, A., and Elliott, D. (2016). Critical ontology for an enactive music pedagogy. *Act. Crit. Theory Music Educ.* 15, 81–121. doi: 10.22176/act15.5.81

van der Schyff, D., Schiavio, A., Walton, A., Velardo, V., and Chemero, A. (2018). Musical creativity and the embodied mind: exploring the possibilities of 4E cognition and dynamical systems theory. *Music Sci.* 1, 1-18. doi: 10.1177/2059204318792319

Varela, F., Thompson, E., and Rosch, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press.

Villalobos, M., and Ward, D. (2015). Living systems: Autonomy, autopoiesis and enaction. *Philos. Technol.* 28, 225–239. . https://doi.org/10.1007/s13347-014-0154-y, doi: 10.1007/s13347-014-0154-y

Wallas, G. (1926). *The Art of Thought*. London: Jonathan Cape.

Weber, A., and Varela, F. (2002). Life after Kant: natural purposes and the autopoietic foundations of biological individuality. *Phenomenol. Cogn. Sci.* 1, 97–125.

Webster, P. R. (1987). "Refinement of a measure of creative thinking in music," in *Applications of Research in Music Behavior*, eds C. Madsen and C. Prickett (Alabama: University of Alabama Press), 251–257.

Webster, P. R. (1992). "Research on creative thinking in music: The assessment literature," in *Handbook of Research on Music Teaching and Learning*, ed. R. Colwell (New York, NY: Schirmer Books), 266–280.

Webster, P. R., and Hickey, M. (1995). Rating scales and their use in assessing children's compositions. *Quart. J. Music Teach. Learn.* 6, 28–44.

Weisberg, R. (1993). *Creativity: Beyond the Myth of Genius*. New York, NY: WH Freeman.

Wenger, E. (2002). *Cultivating Communities of Practice: A Guide to Managing Knowledge*. Cambridge, MA: Harvard University Press.

Whittall, A. (2017). "Composer-performer collaborations in the long twentieth Century," in *Distributed Creativity: Collaboration and Improvisation in Contemporary Music*, eds E. Clarke and M. Doffman (Oxford: Oxford University Press), 21–36.

Wiggins, G. A. (2012). The mind's chorus: creativity before consciousness. *Cogn. Comp.* 4, 306–319. . https://doi.org/10.1007/s12559-012-9151-6., doi: 10.1007/s12559-012-9151-6

Wilson, G. B., and MacDonald, R. A. R. (2017). The construction of meaning within free improvising groups: a qualitative psychological investigation. *Psychol. Aesthet. Creat. Arts* 11, 136–146. doi: 10.1037/aca0000075

Wong, S. S., and Lim, S. W. (2017). Mental imagery boosts music compositional creativity. *PLoS One* 12:e0174009. doi: 10.1371/journal.pone.0174009

Wopereis, I. G. J. H., Stoyanov, S., Kirschner, P. A., and Van Merriënboer, J. J. G. (2013). What makes a good musical improviser? An expert view on improvisational expertise. *Psychomusicology* 23, 222–235. doi: 10.1037/pmu0000021

Zabelina, D. L. (2018). "Attention and creativity," in *The Cambridge Handbook of the Neuroscience of Creativity*, eds R. E. Jung and O. Vartanian (Cambridge: Cambridge University Press), 161–179. doi: 10.1017/9781316556238.010

Zabelina, D. L., and Andrews-Hanna, J. R. (2016). Dynamic network interactions supporting internally-oriented cognition. *Curr. Opin. Neurobiol.* 40, 86–93. doi: 10.1016/j.conb.2016.06.014

Zatorre, R. J. (2005). Music, the food of neuroscience? *Nature* 434, 312–315. doi: 10.1038/434312a

Zioga, I., Harrison, P. M., Pearce, M. T., Bhattacharya, J., and Luft, C. D. B. (2020). From learning to creativity: Identifying the behavioural and neural correlates of learning to predict human judgements of musical creativity. *Neuroimage* 206, 116311. doi: 10.1016/j.neuroimage.2019.116311

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CONCEPTUAL ANALYSIS
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Gearing Time Toward Musical Creativity: Conceptual Integration and Material Anchoring in Xenakis' *Psappha*

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Understanding compositional practices is a major goal of musicology and music theory. Compositional practices have been traditionally viewed as disembodied and idiosyncratic. This view makes it hard to integrate musical creativity into our understanding of the general cognitive processes underlying meaning construction. To overcome this unnecessary isolation of musical composition from cognitive science, in this conceptual analysis, we approach compositional processes with the analytic tools of blending theory, material anchoring, and enaction. Our case study is Iannis Xenakis' use of sieves for distributing rhythmic patterns in *Psappha*. Though disregarded in previous accounts, the timeline and the gearwheel provide crucial conceptual templates for anchoring Xenakis' idea of time for this score. This case study of conceptual integration templates for temporal representation seeks to gain insight into musical creativity, embodiment, and blending, especially into how virtual interactions with material structures facilitate the construction of complex meanings.

Keywords: conceptual integration, material anchors, time conceptualization, compositional creativity, enaction, science-based composition, Iannis Xenakis

INTRODUCTION

Compositional practices lie at the heart of the inquiry into musical creativity. Understanding the thought processes that drive composers' inventions is one of the major goals of the musicological enterprise and also one of the most difficult to achieve. Musicology was born as a scholarly discipline in the German-speaking world of the nineteenth century, therefore echoing the romantic myth of the lone genius (Montuori and Purser, 1995), a spiritual mediator – typically a European male – between the Muses and the audience. The discipline has since then undergone considerable evolution. Now composition is increasingly regarded as a performative situation within a social milieu, and therefore as one of the multiple facets of musicking (Small, 1998). However, such an approach faces a great challenge when it comes to accessing adequate and sufficient data. While, in a concert, we may observe the behavior of musicians and audience, access to factual compositional practices is generally much more restricted.

Beyond several controlled observations and ethnographic accounts (e.g., Collins, 2005; Donin and Theureau, 2006; Donin and Féron, 2012; Clarke et al., 2013; Donin, 2017; Besada, 2018), composition is still typically studied without making explicit connections with the cognitive processes that make it possible. As a result, composers' creative processes are largely viewed as disembodied and idiosyncratic, and thus considered separately from other cases of creativity, communication, or performance. This makes it very hard to integrate musical creativity into our understanding of the general cognitive processes at work in meaning construction. By viewing musical composition as detached from the mental capacities that underlie all other products of human thought, we are also making musical creativity unnecessarily hard to study.

Here, we argue for an approach that allows us to integrate compositional practices into a general framework for the study of human cognition. Recently, a number of studies have been struggling to place *situated cognition* at the center of our understanding of compositional creativity (e.g., Nagy, 2017; Zembylas and Niederauer, 2018; Schiavio et al., 2020). The terms *situated*, *distributed*, or *grounded cognition*, associated to *4E* (embodied, extended, embedded, and enactive) *cognition*, refer to theoretical positions holding that mental life is inherently tied to its bodily, perceptual, and sociocultural dimensions. Our study seeks not only to expose the situated nature of a seemingly disembodied compositional practice, but also – and perhaps more importantly – to analyze how the cognitive operation of advanced conceptual integration takes this situated-distributed-grounded cognition to a higher level, giving rise to both everyday and sophisticated artistic creativity.

For that purpose, our conceptual analysis will observe Iannis Xenakis' compositional processes for *Psappha* (1975). We will analyze some visual representations and mathematical conceptions, which played a crucial role in the development of the ideas about time that he applied to this piece. This case study is particularly enlightening, because the score was written for an undetermined set of unpitched percussion instruments and with a very restricted use of rhythmic figures. It is therefore easier to just focus on a very reduced list of compositional features, thus exposing the fundamentals of the cognitive processes at work.

BLENDING, ANCHORING, AND TIME

Multiple terms refer to the unrivaled human capacity for integrating disparate experiences and knowledge structures into novel conceptual wholes: *bisociation* (Koestler, 1964), *cognitive fluidity* (Mithen, 1999), or *combinational creativity* (Boden, 2009). The most detailed theoretical framework for this cognitive ability, including its constitutive and governing principles and its patterns across human activities, is known as *blending theory* (Fauconnier and Turner, 2002). Blending theory hypothesizes that conceptual integration proceeds through dynamic mappings across *mental spaces* (Fauconnier, 1985, 1997), i.e., small conceptual packages activated for thought or action.

For example, in the presence of *inanimate secondary visual cues*, such as a carcass or a series of footprints, human beings are capable of activating a mental space with a scene in which a predator is eating the carcass or moving along a trajectory. In an *ad hoc*, adaptive process, humans can map the imagined or remembered scene onto the perceived visual stimulus, establishing correspondences – for instance, connecting the remembered paws of the predator to the perceived shape of the footprints. Crucially, human beings can also form a network that selectively projects elements from the activated mental spaces – in this case, the spaces of the imagined predator and the visible footprints – onto a blended space, where they can be recombined. This recombination leads to the emergence of previously unavailable meanings: the imagined predator now becomes a real one, absent but perhaps hiding in the surroundings, and the marks on the ground now become a *trail* leading toward, where the predator could be (Pagán Cánovas and Turner, 2016).

"Seeing" a fictive or absent reality is easy for humans, but extremely hard for any other species. Some evolutionary advanced primates can produce distinct vocalizations when perceiving different predators (Cheney and Seyfarth, 1988) but cannot generally make sense of inanimate secondary visual cues. Presumably, this imaginative skill was an evolutionary advantage first, and then turned into the basis of all human behavior, which relies on inhabiting realities that cannot be directly perceived, such as cultural conventions, institutions, nations, identities, narratives, and so forth (Fauconnier and Turner, 2002).

Conceptual blending theory hypothesizes that an advanced conceptual integration must indeed start from situated or distributed cognitive processes, but also that it drives those purposes according to its own goals and principles. An aspect of particular relevance for connecting distributed cognition processes with dynamic conceptual integration is the *material anchoring* of conceptual blends (Hutchins, 2005), by means of which the conceptual relations established through an integration network can become materialized, so that perceptual relations *in the blend* become conceptual relations. One example of anchoring in real life is queuing. Many cultures have developed an integration network that has people arriving at a place – for instance, to buy tickets for a concert – in one mental space, and natural numbers, or simply a sequence of slots, in another mental space. People are mapped onto numbers as they arrive, thus establishing correspondences across these mental spaces. If we project these correspondences into a blended space, we can fuse person, arrival event, and number. Now, in this newly integrated scenario, we can combine arrival order and cardinal numbers to come up with ordinal numbers or ordered slots, and we can assign those slots to people, giving rise to turns. Although it might seem trivial, the notion of turn requires a complex integration network of mappings and inferences, with emergent structure that is difficult to grasp at first. Children, for instance, do not arrive at a playground with an innate notion of turn: they need to learn it through social interaction.

But even if we have arrived at a notion of turn, we still do not have queuing. Turns may be difficult to apply if people are scattered. Now the culture, always dynamically defining goals and pursuing greater efficiency, imports additional structure into the network: a linear path with A-to-B directionality. In the blend, we can align people along this path, following their turns. If we convince those people of adopting this cultural practice, they will *enact* (Stewart et al., 2011) this material anchor for the blend and align themselves accordingly. Then we will be able to "see" the turns – who is first or second or fifth – just by looking at their place in the line they have formed. Queueing has now emerged through the anchoring of the turn blend on the linear path (Hutchins, 2005, p. 1559–1562). Material anchors for conceptual blends are everywhere. They can be both perceived and acted upon, and interaction with them is especially useful to organize complex meaning networks, from using clocks, sundials, or calendars to see the time to computer interfaces allowing one to "drag" files into folders.

Blending theory is particularly useful for providing insight into the intricacies of seemingly trivial and conventional cases of meaning construction, including complex concepts such as time. Everyday time expressions across multiple languages – including French and Greek, the major languages of Xenakis – rely on the anchoring of time by means of a mentally-simulated scene that presents a series of selected, *ad hoc* features. All objects (events) are aligned and typically move at a regular, fixed speed; all observers (time experiencers) are on the same spot. Objects can move toward observers along with the timeline, as in a conveyor belt, or be static, observers can move – if objects are static – or be static – if objects move – so that the distances on the path, covered at a regular pace, become durations, and the motion can thus be experienced from an ego-moving, object-moving, or external perspective (Fauconnier and Turner, 2008).

When we refer to any aspect of this network for time motion, we know that we are not talking about a regular physical-motion scene, but about one that has been narrowly defined and prepared to create inferences about time. Once we have this configuration in mind, cultures can create numerous expressions that point to a variety of its properties, using them to create temporal meanings. We can talk about "a long time" (e.g. French *longtemps*, although in Greek quantity is preferred to stretch: πολύ χρόνο, πολύ ώρα), about events "coming" toward observers, such as the "arrival" of spring (*le printemps est arrivé*, ήρθε η άνοιξη), about observers approaching events, as when we are getting close to being on or inside a date-location (*Nous sommes déjà en 2020*, είμαστε πια στο 2020), and about time passing (*let temps est passé*, έχει περάσει ο χρόνος), from which the nouns and adjectives referring to time as *past* or *to come* – the meaning of the Latin word *futurus*. Ample evidence from linguistics and psychology has exposed the detailed ways in which these mappings, alongside the cross-linguistic variations for activating them and the perceptual patterns to anchor them, influence human behavior in multiple time-related tasks and creative activities across cultures (Boroditsky and Ramscar, 2002; Weger and Pratt, 2008; Fuhrman and Boroditsky, 2010; Coulson and Pagán Cánovas, 2013; Pagán Cánovas et al., 2015).

Material anchors are useful for discussing agency in musical practices (Zbikowski, 2019), such as the presence of timelines in composition (Besada and Pagán Cánovas, 2020). In the forthcoming discussion of the compositional practices around *Psappha*, we analyze material anchoring in a complex conceptual integration network for time, built *ad hoc* to serve the purposes of music composition, but nonetheless based on the basic patterns that we have just outlined. Our approach will expand upon current knowledge of time and enaction in contemporary music (Kozak, 2020) from the side of composition. For this, we will be relying on visualizations from Xenakis' sketches as well as on his theoretical writings. Before we discuss how the principles and patterns of conceptual integration make his creative process possible, we introduce sieve theory and outline Xenakis' personal interpretation of it. Then, we analyze the application of sieves to the composition of *Psappha* through the interaction of two material anchors for complex time blends: the timeline and the gearwheel.

FROM SIEVE THEORY TO XENAKIS' COMPOSITIONAL SIEVES

Our case study is a specific implementation of Xenakis' sieve theory. The composer used the term "gearwheels" to refer to his adaptation of this particular mathematical method *in Psappha* (Barthel-Calvet, 2000, p. 169). Among the sketches preserved for this score, there is one in which he wrote "*roues dentées = cribles*" – i.e., "gearwheels = sieves" in French – (**Figure 1**). Another sketch shows a drawing of schematic gearwheels (**Figure 2**). The few specific studies concerning the sieves for *Psappha* (Flint, 1993, 2001) are based on the scrutiny of these sketches but contain no mention to the subject of gearwheels. They probably went unnoticed or were considered as anecdotal by the scholar. After all, wheel-like diagrams were mainly related to other issues he dealt with in the early 1950s, since he started to reconsider serial music techniques for his own compositional purposes (Barthel-Calvet, 2003, 2011).

The transfer from visual elements to musical ideas in Xenakis' creative practices has been already discussed, for his architectural experiences (e.g., Barthel-Calvet, 2001, 2009; Kiourtsoglou, 2017) as well as for the computational ones (e.g., Weibel, 2020). Even a brief approach to the anchoring features of Xenakis' compositional practices has been recently published (Besada, 2020). By contrast, we have not found detailed discussions of visualizations in the application of sieves.

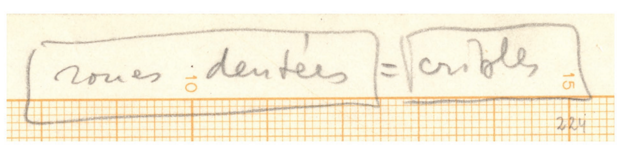

FIGURE 1 | Reference to gearwheels in Xenakis' sketches for *Psappha*. © Iannis Xenakis' family. Reproduced by permission.

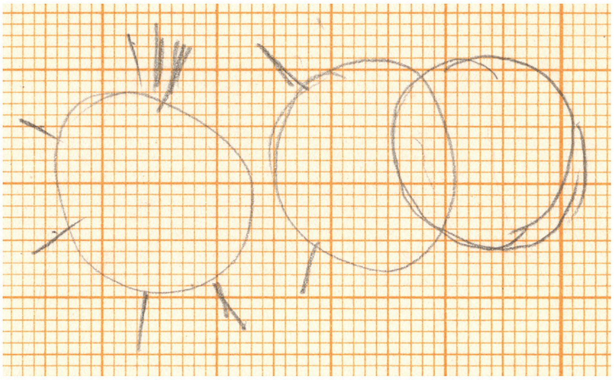

FIGURE 2 | Gearwheel outlines in Xenakis' sketches for *Psappha*. © Iannis Xenakis' family. Reproduced by permission.

Mathematical Roots

Sieve theory is a branch of number theory that estimates the members of a subset of natural numbers or integers, sometimes also predicting the relative size of the subset, by means of iterative filtering algorithms (Halberstam and Richert, 1974; Greaves, 2001; Cojocaru and Murty, 2006). Its most famous case is the sieve of Eratosthenes for finding prime numbers (Bays and Hudson, 1977). We may summarize it in a few steps. Ignore number 1 and keep number 2, it is a prime number. Cross out all multiples of 2 – i.e., even numbers – and continue to the next natural, which is 3, again a prime number to be kept. Cross out all multiples of 3 – unless already eliminated, e.g., 6 – and continue to the next natural, 4, which had already been taken out. Then jump to the next natural, which is 5, and iterate the process *ad infinitum*.

Apparently, Xenakis' sieve-based compositional technique would be applying strictly abstract mathematical operations to the organization of sound. He rarely provided descriptions based on visual imagery in his remarks upon sieves – although we reproduce a very eloquent example below. Just like many other ideas developed by contemporary composers, this technique may at the first seem disembodied, even disconnected from musical creativity itself, at least in the initial stages of composition. However, goal-oriented, embodied cognitive processes are at work since the inception of the composer's imaginative process for *Psappha*. Seemingly exotic – from the cognitive point of view – examples such as Xenakis' sieves share the basic cognitive operations of conceptual integration with any other product of higher-order human cognition. With other, less unusual instances of temporal meaning construction, such as making sense of a clock or a timeline or of conventional expressions of time-related feelings or intentions, Xenakis' sieves also share much more specific patterns that arise when conceptual integration meets specific purposes, contexts, and practices. But before we delve into those patterns, let us examine his adaptation of sieve theory for compositional purposes and its connection with standard time concepts as well as with his own ideas about time in music.

Xenakis' idea while developing his compositional sieves was to hold analogies between musical features – such as the distribution of pitches and beats – with the numerical intervals of complex mathematical sieves admitting a decomposition into elemental cyclic sequences, unlike the Eratosthenes method, which goes on *ad infinitum*. He developed this method since the mid-1960s and discussed it through several essays (Xenakis, 1965, 1966, 1967, 1968, 1988, 1990) without any reference to the term "gears." One of his articles provided an important account of several compositional choices around his piece *Nomos Alpha* (1965–1966) for cello solo that helped several analysts delve into its mathematical features (Vandenbogaerde, 1968; DeLio, 1980; Vriend, 1981; Solomos, 1997; Peck, 2003). Other scholars have equally approached his sieves seeking to analyze further pieces within Xenakis' oeuvre (e.g., Flint, 1993, 2001; Bertocchi, 2001; Pace, 2001; Squibbs, 2002, 2003; Exarchos, 2007; Gibson, 2011, p. 81–114), to understand the mathematical details of the composer's approach (e.g., Gibson, 2001; Jones, 2001; Exarchos, 2009), to contextualize the relationships between this approach and others he already developed (e.g., Barthel-Calvet, 2012; Hoffmann, 2019), to derive computational models (e.g., Agon et al., 2004; Ariza, 2005), to borrow sieves for their own compositional purposes (e.g., Tipei, 1987, 1989), or as a formal framework for analyzing other repertoires (Noll et al., 2006). To the best of our knowledge, there is only one work providing cognitive remarks upon Xenakis' sieves, and again in quite general terms (Besada, 2019, p. 265–267).

Compositional Bases

Xenakis used sieves for several creative purposes. His first article on this topic sought to provide a universal method for describing the pitch structure of any scale (Xenakis, 1965). Subsequent articles on sieves equally focused on pitches, but he also remarked that the formalization might serve to organize other features of sound (Xenakis, 1966, 1967, 1968). His last two essays on sieves put the emphasis on time (Xenakis, 1988) and on their rhythmic exploitation (Xenakis, 1990). The former articles are the most relevant for understanding the axiomatic background of Xenakis' perspective. His starting formal step was to adapt Peano axioms – i.e., the logical foundations for the arithmetic of natural numbers (Segre, 1994) – within a musical context:

> "*Preliminary terms*. O = the stop at the origin; n = a stop; n' = a stop resulting from elementary displacement of n; D = the set of values of the particular sound characteristic (pitch, density, intensity, instant, speed, disorder…). These values are identical with the stops of the displacements.
>
> *First propositions (axioms).*
>
> 1. Stop O is an element of D;
> 2. If stop n is an element of D then the new stop n' is an element of D;
> 3. If stop n and m are elements of D then the new stop n' and m' are identical if, and only if, stops n and m are identical;
> 4. If stop n is an element of D, it will be different from stop O at the origin;

5. If elements belonging to D have a special property P, such that stop O also has it, and if, for every element n of D having this property the element n' has it also, all the elements of D will have the property P" (Xenakis, 1992, p. 194).

Already at this early stage, we find a dynamic, goal-oriented reuse of the mathematical notions for establishing musical concepts, which necessarily rely on embodied or sensorimotor processes for their structure. Indeed, for the case of pitch, this reinterpretation of Peano axioms depends on schemas resulting from basic spatial cognition such as scalar structures or motion along a path (Besada, 2019, p. 266), on which arithmetic is generally grounded (Lakoff and Nuñez, 2000, p. 68–74). This grounding is eloquently formulated through mental imagery engaging with a material anchor in one of Xenakis' essays. He mentally visualized the organization of pitches following the total order of natural numbers as "a strip of paper with equidistant holes, which when placed over a special piano keyboard will locate keys separated by any elementary displacement" (Xenakis, 1966, p. 49). So far, the spatial cognition schemas applied to these conceptualizations were used to organize relations between sounds without introducing time.

When the sieve technique was used for rhythmic organization, the mental pattern of the timeline as a material anchor for temporal meanings arose. We can see it in another text by Xenakis on sieves, where he used the major standard mappings that shape the blended scenario of spatialized time recurrent across conventional conceptualizations: motion along the path maps onto time itself, which can now pass or flow; dots on the timeline path map onto events, which become landmarks that can thus be visualized in a sequence, a basic function of the timeline. As the composer said, "[t]hanks to separability, […] events can be assimilated to *landmark points* in the flux of time" (Xenakis, 1992, p. 264). In one of his earliest articles, he had already mentioned, quite explicitly, another standard mapping for the spatialized-time blend: the correspondence between distances on the line and durations. This blend gives rise to expressions such as "long/short time," to the segmentation of timelines into periods, to proportional divisions in linear or circular calendric representations, and so forth. In this text – first published in German (Xenakis, 1956) and thus prior to the composer's conception of musical sieves – time is "a straight line on which the points corresponding to the variations of other components [of a phenomenon] are marked"; consequently "[t]he interval between two points is identical with the duration" (Xenakis, 1992, p. 12).

Right from the start, Xenakis' ideas about the organization of time in his musical compositions needed to rely on the timeline and other standard conceptions of spatialized time, all of them grounded in embodied cognition and made possible by conceptual integration, including processes of extended cognition for anchoring thought on perceptual information. Awareness of these templates for conceptual integration is crucial for understanding how any individual operates on them to serve specific purposes, and in this case, how Xenakis exploited their possibilities and explored their boundaries, in his effort to create innovative time effects of aesthetic value. Examining such innovative practices provides crucial insights precisely on the boundaries being pushed, on the general nature of these representations, and on the cognitive operations underlying creativity and meaning construction in general. Within this "timeline context," it is now useful to examine how Xenakis moved forward in his technique of sieves, in a goal-oriented process that is partially structured by the mental timeline and the drive toward achieving musical effects, through the analogical arrangement of events as landmarks on a number line.

Xenakis' reinterpretation of Peano axioms is followed in his essays by a description of methods for obtaining families of subsets of numbers and for operating with them. The elemental subsets are built *via* what mathematicians define as congruences of modular arithmetic (Jones, 1964). As the composer explained, "[t]wo integers x and n are said to be congruent modulo m when m is a factor of $x - n$" (Xenakis 1992, p. 195). For instance, 13 and 1 are congruent modulo 12 because 13–1 equals 12. Modular relationships induce classes of equivalence – i.e., subsets of related elements – on natural numbers. For instance, the classes of natural numbers congruent with 1 modulo 12, and with 5 modulo 8 are:

$$12_1 = \{1,13,25,37,49,61,\ldots\}$$

$$8_5 = \{5,13,21,29,37,45,\ldots\}$$

We are preserving one of Xenakis' most common notations, wherein the large number stands for the modular constant, and the sub-index for the smaller representative of the class – the residue. Each residual class of equivalence incorporates a sub-periodicity – a particular kind of sieve – within the progression of naturals.

Xenakis' next step was to carry out basic Boolean operations on the elemental sets, mainly *union* – the gathering of elements – and *intersection* – the filter of common elements. In addition, he also took into account the *complementary set*, i.e. the one with the lacking naturals within the starting set. These formal operations reflect container image schemas and have therefore an embodied origin (Lakoff and Nuñez, 2000, p. 121–131). Therefore, we have not actually been dealing with disembodied processes at any point of this creative development. Considering the previous examples, their respective union and intersection are:

$$12_1 \cup 8_5 = \{1,5,13,21,25,29,37,45,49,\ldots\}$$

$$12_1 \cap 8_5 = \{13,37,61,\ldots\}$$

Finally, Xenakis added further transformations beyond basic logics of mathematical set theory, which he coined as *metabolae*. His main metabolae entailed the modification of the modular numbers or indices. For instance, 13_1 would be a metabola of 12_1, just replacing number 12 by 13 but leaving sub-index 1 invariant.

INTEGRATION AND ANCHORING IN THE SIEVE TECHNIQUE FOR XENAKIS' *PSAPPHA*

Let us pursue for a moment a strictly formal analysis of this compositional technique, without taking cognitive processes into consideration. Among Xenakis' sketches for *Psappha*, one of them reproduces the complex calculations for the sieve – henceforth S – that he used for distributing the beats during the 40 first pulses of his score. Flint (1993, p. 232) transcribed Xenakis' formulae as follows:

$$\begin{aligned} S = & \left[(8_0 \cup 8_1 \cup 8_7) \cap (5_1 \cup 5_3)\right] \cup \left[(8_0 \cup 8_1 \cup 8_2) \cap 5_0\right] \cup \\ & \cup \left[8_3 \cap (5_0 \cup 5_1 \cup 5_2 \cup 5_3 \cup 5_4)\right] \cup \\ & \cup \left[8_4 \cap (5_0 \cup 5_1 \cup 5_2 \cup 5_3 \cup 5_4)\right] \cup \\ & \cup \left[(8_5 \cup 8_6) \cap (5_2 \cup 5_3 \cup 5_4)\right] \cup \left[8_1 \cap 5_2\right] \cup \left[8_6 \cap 5_1\right] \end{aligned}$$

The expression above is extremely complex. Flint proceeded by applying the distributive property – i.e., by ungrouping the expression for obtaining its elementary constituents. It leads to a large list of 27 intersections of two sieves each. As 8 and 5 are coprimes – i.e., they do not share a common prime factor – there is only one solution for each sieve from 0 to 39. Finally, she gathered all the elemental solutions in a single set (Flint, 1993, p. 232; we add number 22, which she forgot to include in the list):

$$S = \left\{ \begin{matrix} 0,1,3,4,6,8,10,11,12,13,14,16,17,19,20, \\ 22,23,25,27,28,29,31,33,35,36,37,38 \end{matrix} \right\}$$

If we stick to this type of analysis, the insight gained into the compositional process is limited. We already showed that Xenakis had to rely on standard, everyday integration templates for forming time concepts and for anchoring them on perceptual structures in order to interact with them productively. Without the timeline structure, and without the aesthetic motivation to distribute events along a timeline following certain patterns, we would have never had any sieve technique to apply to the composition of *Psappha* in the first place. Now, in order to understand how Xenakis got to his final compositional choices, we need to take into account his explicit reference to gearwheels. This second material anchor provides the sieves with a material structure that turns them into an actionable object. The resulting mental space, in which gearwheel-sieve and timeline can now interact, gives rise to a rhythmic structure that would have been unavailable from either timeline or sieves separately.

Sieves, Gearwheels, and the Elemental Cycles

As we said, Flint's analysis disregarded the textual and visual references to gearwheels in Xenakis' sketches. However, if we bring in the "materialization" of sieves as gearwheels, new light can be shed on Xenakis' creative process. For one thing, the material anchoring of the sieves, and the manipulations it affords, becomes a central part of the analysis. The choice of gearwheels to anchor sieves is well motivated in cognitive terms, since it is grounded on a set of generic properties shared by both sieves and gearwheels. Material anchors are not arbitrary symbols but objects or spatial configurations that arise from interactions with the world that have been found to facilitate the cognitive process. Just like cultural evolution leads to solutions such as the timeline or the queue, whose affordances serve chronology and sequence arrangement, Xenakis got to the gearwheel because of its potential for matching the cyclic sequences that he was pursuing with the sieves.

Circular templates for representing musical rhythm over time are found in essays of ethnomusicology (e.g., Becker, 1980; Anku, 2000), music theory (e.g., Toussaint, 2005, 2013; Benadon, 2007), and the psychology of music (London, 2004, p. 64–69). These representations are consistent with the ubiquity of circular or spiral schemas that cultures use to anchor natural cycles (Overton, 1994; Yamada and Kato, 2006; Laeng and Hofseth, 2019). All these anchors cohere with the blending template that allows human to compress regular sequences of events into cycles, giving rise to our cyclic notions of day, year, and so forth (Fauconnier and Turner, 2002, p. 195–198). All these representations are adjusted to the main goal of dividing the continuous flow of time – within or without music – into discrete units with which it is possible to operate. Xenakis goes one step further here. By creating a complex interaction of the gearwheel and the timeline anchors, he produced a combination of cyclic and linear time that gave rise to the particular rhythmic structures in *Psappha*.

Let us now examine how Xenakis' cyclic model works. Modular arithmetic is generally introduced to young students as the "clock arithmetic." Consider the sieve 12_1 provided above and think of a clock sphere. The first two elements of this sieve are 1 and 13; we read both values in the same position on the clock, for 1AM and for 1PM. Applying analogous protocols, Xenakis' elemental sieves for S can be equally projected onto a circular template akin to the clock shape, but modifying the number of its equal divisions. Consider for instance the elemental sieves modulo 5 in S. They can be anchored onto a circumference split into five equal arcs, starting with a point in a position equivalent to noon-midnight in a clock. This point may receive the label 0, and the process of labelling with values 1, 2, 3, and 4 is performed clockwise. With this support, any elemental sieve modulo 5 is amenable to a material representation. For instance, the sieve 5_0 is represented by a mark on point 0. Similarly, the union of elemental sieves sharing the same modulo is easily combined within the same support. For instance, the union of elemental sieves $(5_2 \cup 5_3 \cup 5_4)$, which is found in the previous formula, is represented by marks on the points 2, 3, and 4.

It is easy to visualize a clock hand – for instance marking seconds – cyclically moving through the aforementioned sieve and union of elemental sieves. The person mentally performing this action may also have an internal feeling of beats when the clock hand reaches a marked point. It would be a beat every 5 s for the sieve 5_0, and cycles of three consecutive beats followed by two unbeaten pulses for the union $(5_2 \cup 5_3 \cup 5_4)$. As the notion of "clock arithmetic" is quite common, Xenakis was probably aware of it; he opted however for comparing his compositional process with gearwheels.

These devices are a substantial part of mechanical clocks and their rotational motion image is widespread in Western culture. Unlike the usual shape of clocks, which is often a smooth, unaltered circumference, gears have teeth. Gear teeth exist for interaction with other devices or surfaces and may leave marks. This is where the motivation to interact with the timeline kicks in.

In the novel mental space resulting from the integration of these two already complex blends, the affordances of the gearwheel-sieve meet those of the musical timeline. Within the context of Western musical notation and its horizontal timeline, where figures are annotated as landmarks on a two-dimensional surface, it is not difficult to mentally imagine a gearwheel freely rolling on such a surface and leaving a line of marks or fixedly rotating on itself to imprint the marks on a scroll sheet unfolding a stave or any other akin representation. We have visualized this idea in **Figure 3**: the upper circle stands for the elemental sieve 5_0, in which the mark on point 0 is represented by a square, for transforming the previous clock-like template into a gear-like one. We can imagine the marked circle rolling counterclockwise under the timeline and dropping a landmark point – "on the flux of time," as Xenakis could have said – when the point of the sieve cyclically meets the straight timeline. We have unfolded the process eight times for matching with the first 40 pulses of *Psappha*. The diagram below in the same figure is an equivalent representation for the union $(5_2 \cup 5_3 \cup 5_4)$. For these kinds of "scrolling motion" mental images, the gear-like shape proves more suitable than that of the clock.

The Gearwheel-Timeline System in Xenakis' Sieve-Based Composition

Now let us examine whether this idea of enaction through imaginary material anchors can illuminate some of Xenakis' choices during his compositional process. In **Figure 3**, we have just dealt with sieves made of elemental components sharing a modulo. In the mathematical expression for *S*, all these unions are expressed within parentheses. Additionally, *S* also incorporates elemental sieves with modulo 8. Elemental sieves or blocks of sieves sharing modulo 5 are confronted with similar objects sharing modulo 8 *via* intersection in an upper level – bounded within brackets. It is the case, for example, of the subexpression $\left[(8_5 \cup 8_6) \cap (5_2 \cup 5_3 \cup 5_4)\right]$, which is represented in **Figure 4**. Its upper diagram simply reproduces the lower diagram of **Figure 3**. Below, a similar configuration is provided for the union $(8_5 \cup 8_6)$. The unfolding marks over parallel timelines can be used for estimating the intersection, just by checking the aligned landmark points dropped on both straight lines.

We have reproduced the result of the intersection in the lower diagram of **Figure 4**. Instead of accompanying its timeline with its implicit forty-teeth gear-like template, we have represented it with a diagram, which stands for the interaction of the gears above. The intersection can still be obtained through extremely complex operations based on Boolean algebra, as shown above, but Xenakis' mental image of gearwheels, which made its way to one his sketches, provides a plausible insight into how the creative conceptualization may have been imagined. A dynamic interaction with familiar material anchors is just as possible virtually as in a scenario of direct perception. Whether Xenakis only used mental imagery or also enacted the gearwheel-timeline interaction in further drawings unavailable to us, we cannot know, but it is indeed cognitively plausible to imagine both gears rolling in parallel across the same timeline. In this situation, they would only drop a landmark point onto the straight line when both gears are simultaneously activated for doing so.

We are ready for jumping to the uppermost level of Xenakis' sieve. Again, it is in principle possible to obtain the same results through complex operations based on Boolean algebra, but now the exclusive use of that option is becoming increasingly unrealistic, because it requires a much stronger cognitive workload than the gearwheel alternative. It would be similar to a particular case of ship navigation, not assisted by computational devices, where humans would choose to calculate relative positions, bearings, and routes exclusively through arithmetic operations, without resorting to the perceptual location of landmarks and the customary multimodal interaction with charts, scales, triangles, and so forth (Hutchins, 2011). The enactive solution, whether Xenakis actually made drawings or ran it through mental simulation, is not only much more cognitively plausible but also more realistic when it comes to doing creative work with time concepts, since it allows for a dynamic interaction with one's own ideas about temporality and rhythm as the creative process unfolds. Therefore, in this step, the union entails the simultaneity of several pairs of

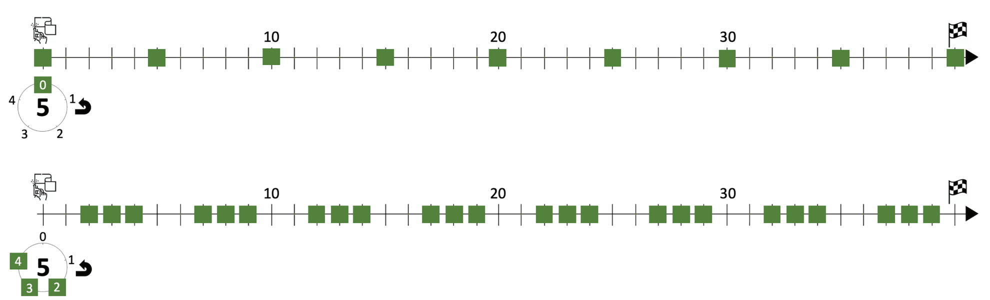

FIGURE 3 | Schematic representation of the scrolling motion of elemental sieves.

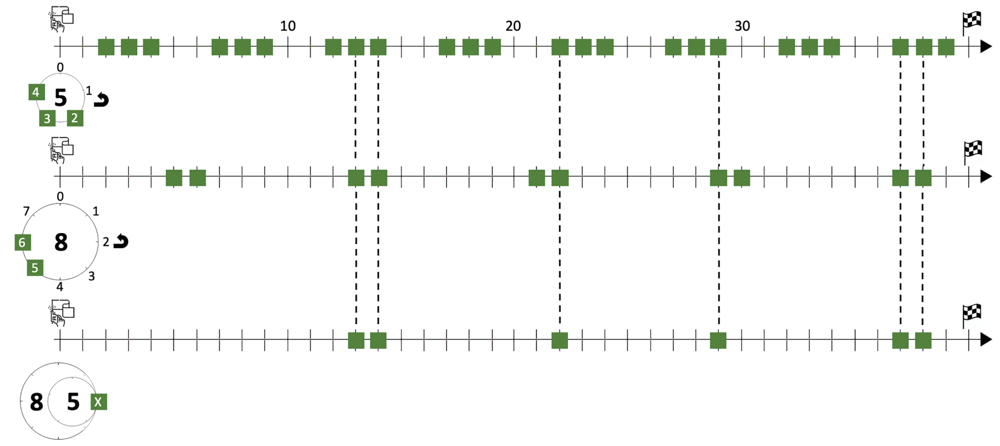

FIGURE 4 | Schematic representation of the scrolling motion of elemental sieves and their intersection.

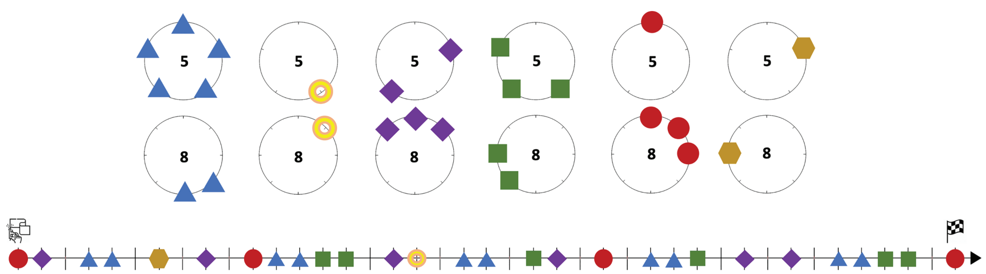

FIGURE 5 | Gearwheel representation of the elemental sieves leading to *S* and their unfolding onto a timeline.

gearwheels – as those we already provided in Image 4 – conforming a kind of "complex clockwork" to be confronted with the timeline. Every pair of gears drops its landmark points, and the assembly of them all completes the action of the sieve. The formula provided above, in which there are seven bracketed subexpressions, admits the merge of two of them by means of the distributive property. In doing so, *S* is reduced to six subexpressions, which are depicted in **Figure 5**, with the following color-shape code for both the teeth of the gears and the landmark points on the timeline:

- Blue triangles: $[(8_3 \cup 8_4) \cap (5_0 \cup 5_1 \cup 5_2 \cup 5_3 \cup 5_4)]$.
- Yellow rings: $[8_1 \cap 5_2]$.
- Purple diamonds: $[(8_0 \cup 8_1 \cup 8_7) \cap (5_1 \cup 5_3)]$.
- Green squares: $[(8_5 \cup 8_6) \cap (5_2 \cup 5_3 \cup 5_4)]$.
- Red circles: $[(8_0 \cup 8_1 \cup 8_2) \cap 5_0]$.
- Ocher hexagons: $[8_6 \cap 5_1]$.

Enaction through gearwheels is by no means incompatible with the use of modular arithmetic, which is necessary for calculating the accurate elemental values of the sieve step by step. Indeed, Flint's paper summarizes the calculations found in Xenakis' preserved sketches. But, as we are showing, exclusive use of this non-enactive procedure becomes more implausible as we delve into the intricacies of the compositional process. This hypothesis receives more support when we look into the "beat-zipping effect" in the opening of *Psappha*.

Gearwheels as Zippers

Xenakis' score for *Psappha* is not written within the current standards of Western music notation. The composer gave Sylvio Gualda – the percussionist Xenakis wrote the piece for – a fair copy with vertical segments like note stems, akin to the notations on graph paper of his sketches, but Gualda found this document too hard to read (Lalitte, 2018, 19′01″–19′40″). Consequently, at Gualda's request, Xenakis had to opt for a new notational protocol, which is in addition more helpful, visually speaking, for our cognitive discussion. Each system of the published score – as the first one shown in **Figure 6** – is almost a grid in which circled marks akin to noteheads are distributed. In this passage, each horizontal line, namely A1, A2, A3, B1, B2, and B3, is assigned to a wooden or membranophone instrument. These lines should be regarded as simultaneous timelines, just like those in our previous figures. They resemble the time-unit box systems developed by ethnomusicologists (Koetting, 1970). In addition, Xenakis

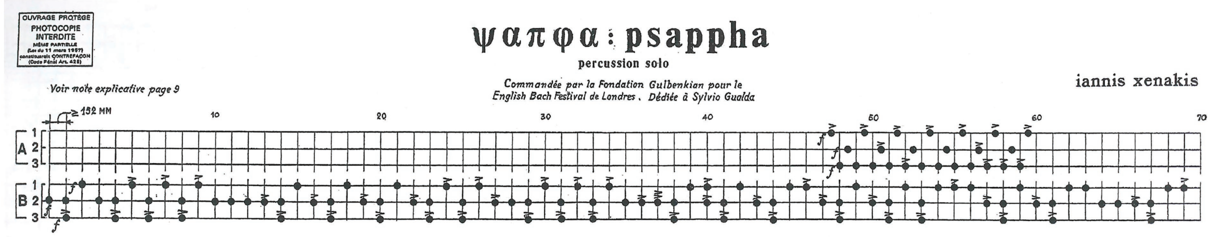

FIGURE 6 | *Psappha* (first 70 pulses) by Iannis Xenakis. © 1976 Éditions Salabert. Reproduced by kind permission of Universal Music Publishing France and Éditions Salabert.

explicitly anotated that the minimal segment of timelines stands for the metronomic pulse 152 MM or faster. The displayed noteheads therefore represent the landmark points Xenakis assigned for each beat that the percussionist has to play. Other symbols in the score for dynamics and articulation are more conventional.

We may henceforth ignore the lines for instruments A1, A2, and A3 as they do not come into the scene during the first 40 pulses and are not an outcome of any sieve. Conversely, the music during this lapse of time for instruments B1, B2, and B3 strictly depends on sieve *S*. Just compare the straight timeline in **Figure 5** and the noteheads Xenakis wrote for instrument B2 from pulse 0 to pulse 39. They are exactly in the same place, which means that the outcome of the sieve has been directly transcribed into the line for this instrument. The distribution of noteheads for instruments B1 and B3 during this passage is a consequence of that first choice. On the one hand, compare the lines for instruments B1 and B2: there are noteheads for instrument B1 exactly in the pulses, which are not beaten by instrument B2. On the other hand, compare the lines for instruments B1 and B3: the lower layer replicates the beat pattern of the upper one, but preceding it by one pulse.

Instrument B3 has of course an impact on the aural appearance of the passage, but we will now focus on the relationship between instruments B1 and B2. From the perspective of Boolean algebra, it is possible to describe the elements matching with the noteheads for instrument B1 as the complementary set of the sieve *S*, that is, all the elements of a universal set – here pulses from 0 to 39 – which do not belong to the sieve. From the perspective of the gear-like templates, Xenakis' choice can be regarded as two meshing gearwheels. It is indeed one of the main reasons justifying the shape of these devices: when two gearwheels mesh, their respective teeth are counterbalanced, i.e., each tooth of a gear occupies the empty space between two contiguous teeth of the confronted gear. Consider the mental image of linearly unfolding these gear-like shapes: they would fasten like zippers.

It is true that complementarity in Boolean terms played an important role in the conception of Xenakis' early pieces (Xenakis, 1963, p. 200–208; Squibbs, 2000; Wannamaker, 2001). As stated in a previous section of our analysis, Xenakis also mentioned complementarity in his theoretical essays as a tool for calculating sieves, but rather as a secondary feature of Boolean algebra. Indeed, the union and the intersection were ubiquitous operations within Xenakis' sieves; conversely, complementary sets were not always present. Among the cases in which complementarity was summoned in this compositional context, *Psappha* stands as the most eloquent one, aurally speaking, because of its straightforward implementation.

This effortless approach, mathematically speaking, to the complementary set of a complex sieve is precisely found in the piece that Xenakis expressly related to gearwheels in its compositional sketches. We surmise therefore that the gear-like template was crucial for conceiving a kind of "beat zipping" between instruments B1 and B2 in the opening of *Psappha*. Once more, enaction through material anchors provides a plausible cognitive account of how Xenakis' thought may have led to this choice. The use of modular arithmetic would have been restricted to obtaining accurate calculations where necessary, rather than to reach the beat-zipping insight, which is so readily available from the enactive process.

Metabolae and Prosodic Rhythm

Xenakis also transformed his sieves by means of numerical transpositions or the metabolae technique. The latter was also exploited for *Psappha*. Let us look back to the score excerpt we provided in **Figure 6**. We keep ignoring instruments A1, A2, and A3. As the cycle of the complex sieve finished in beat 39, it could have started again at beat 40. If we compare the music of the very opening beats and what Xenakis wrote from beat 40, it is quite akin; however, after a few strokes, both patterns strongly diverge. This happens because the distribution of noteheads for instruments B1, B2, and B3 currently depends on a metabola of *S*. Xenakis operated a change of the moduli – 8 becomes 7 while 5 becomes 6 – and incorporated a few adaptations for having elemental cycles akin to the former sieve. The formula of his new sieve *S′* is (Flint, 1993, p. 232):

$$
\begin{aligned}
S' = & \left[(7_0 \cup 7_1 \cup 7_7) \cap (6_1 \cup 6_3)\right] \cup \left[(7_0 \cup 7_1 \cup 7_2) \cap 6_0\right] \cup \\
& \cup \left[7_3 \cap (6_0 \cup 6_1 \cup 6_2 \cup 6_3 \cup 6_4 \cup 6_5)\right] \cup \\
& \cup \left[7_4 \cap (6_0 \cup 6_1 \cup 6_2 \cup 6_3 \cup 6_4 \cup 6_5)\right] \cup \\
& \cup \left[7_5 \cap (6_2 \cup 6_3 \cup 6_4)\right] \cup \left[7_1 \cap 6_2\right] \cup \left[7_6 \cap 6_1\right]
\end{aligned}
$$

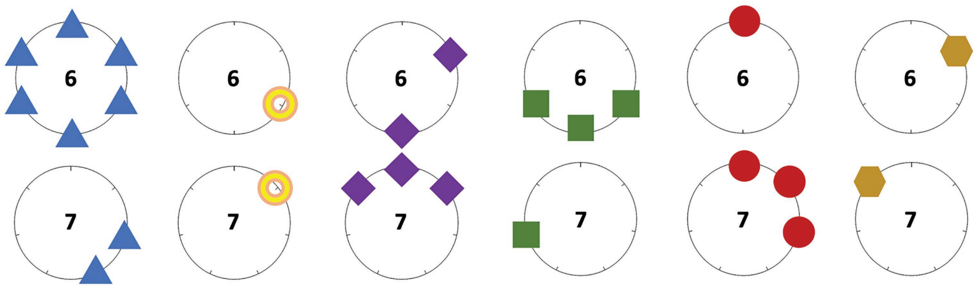

FIGURE 7 | Gearwheel representation of the elemental sieves leading to *S*'.

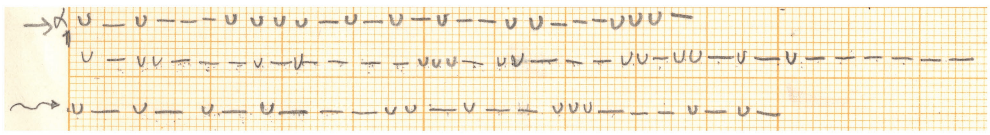

FIGURE 8 | Metric feet in Xenakis' sketches for *Psappha*, also printed in Barthel-Calvet (2000, p. 255 of the appendix). © Iannis Xenakis' family. Reproduced by permission.

As we did before, the expression can be subdivided into six more elemental ones. **Figure 7** provides its visual interpretation through gearwheels. Its resemblance with **Figure 5** deserves some discussion. Metabolae are intrinsically algebraic constructs but, in this context, they can be interpreted through the visual templates. The metabolae operated by Xenakis basically match with respectively adding or subtracting one teeth from the gear in each coupled system, for finally merging them all.

We continue ignoring instruments A1, A2, and A3. Although the passage from beat 0 to 39 and the one from 40 to 79 are quite different in terms of distribution of noteheads, the listener may find strong resemblances, aurally speaking. Of course, the limitation of pulsed beats to only three instruments is the main reason for this, but a closer look to the score allows us to also detect structural parallels. Just consider the first three pulses: the initial one is beaten by instrument B2, the second one is simultaneously beaten by instruments B2 and B3, and the last one is beaten only by instrument B1. This rhythmic cell in pulses 0–2, which may be perceived as an iambic pattern, is repeated 14 more times within the passage in **Figure 6**: in pulses 3–5, 13–15, 16–18, and so on.

The choice of the Greek metrical foot for defining this pattern is not our suggestion. Surely informed by Xenakis' sketches (**Figure 8**), Flint's analysis mentions "iambic-based schemes" and provides a table of their distribution with the conventional ∪__ notation for iambs (Flint, 1993, p. 229). Psappha is the Aeolic name of Sappho: Xenakis's title honors the famous Greek poet. However, the rhythmic patterns in *Psappha* are not imitating the hendecasyllabic verses of a Sapphic stanza (Mâche cited in Barthel-Calvet, 2000, p. 317).

Although Flint discussed the formal aspects beyond the emergence of iambic feet, she did not really problematize this issue. First, Xenakis' sieves were chiefly aimed at this purpose. If we count the elements of *S*, there are 27 numbers, which is about two-thirds of the whole cycle of 40 beats. A distribution of two-thirds of beats for instrument B2 – along with the mechanism for obtaining those for instruments B1 and B3 – is the most suitable quantity for obtaining a large number of iambic patterns. A smaller or a bigger size would entail, statistically speaking, less iambs. Second, the effect of the metabola discussed above and other methods – beyond the sieve technique (Flint, 1993, p. 230) – make iambic feet spread in an unpredictable way. *Psappha*'s combination of recurrence and unpredictability, with great frequency of iambs, allows for an evocation of the flow of tonic and non-tonic syllables in speech, especially in the prosody of Indo-European languages, including French and Greek. It also perhaps resembles the sequences of long and short syllables in ancient Greek, with or without a metrical pattern.

What Xenakis' precise goal was, that we do not know, but the existence of a purpose in the manipulation of the sieves seems evident. Once more, we see that the engagement with the material anchors is purposeful, driven by the search of a particular musical effect rather than mechanically applying abstract formulations. This goal-orientedness is a central characteristic of any blending or anchoring process. Another defining feature of conceptual integration, which we can see here quite well, is dynamicity: goals and conceptual operations mutually modify one another as the creative process unfolds. This "emergent design" allows the composer to opportunistically seize the new possibilities discovered through interactive engagement with others, with objects in the environment, or with virtual structures that present interactive affordances, such as material anchors. Xenakis' metabolae technique for adjusting his sieves is thus reflecting the opportunism of conceptual integration that we can witness in so many human activities, and which allows insights to arise across musical performance, face-to-face communication, and so many other examples of joint action, in complex collective dynamics such as the company culture or the film set, or in the individual acts of creation that are typical in music composition, literature, or the plastic arts.

CONCLUSION

The understanding of general cognitive processes proves crucial for explaining the sophisticated, *ad hoc*, seemingly opaque compositional choices made by Xenakis in *Psappha*. To expose the connections between Xenakis' manipulation of sieves as gearwheels and conventional time representations, we have used the frameworks of blending theory and enaction, and the notions of network integration and material anchoring. Quite surely, alternative views could be proposed, and we are also confident that future developments will result in improved theories providing better accounts of the intricacies of human creativity and imagination. But what cannot be doubted is that an understanding of the general cognitive abilities underlying all meaning construction processes is necessary to reach any fruitful insights into creative practices in any particular domain, in this case music.

This also includes an understanding of the generic purposes that guide cognitive operations, which are always dynamic and goal-oriented. In this case, it is crucial to understand the overarching goal of any integration of material and conceptual structures, which is always to compress the manifold, scattered information dispersed across the mental network – multiple time-space mappings, the standard properties of the timeline, the complex operations of sieves, and so forth – into a scene at human scale, where interaction and manipulation can produce conceptual outcomes in a straightforward way – actioning gearwheels to obtain rhythmic patterns. In this sense, Xenakis' sieve-wheels are driven by the same forces that give rise to the clock, the timeline, or the practice of queuing. To analyze these processes, visualizations acquire great value as data. The detailed knowledge about a composer's ideas and theoretical proposals needs to be combined with the close examination of sketches and other ethnomusicological procedures, such as the study of gesture in recorded interviews. We need to integrate all these methods to gain insight into the domain of compositional practices, which is perhaps the hardest to tackle in the field of musical creativity.

Of no less importance, we must also flip the coin and look at the other side of the methodological argument. The detailed cognitive analysis of compositional practices, especially if they are as intricate and non-typical as the ones displayed by Xenakis in our case study, is necessary not only to understand musical creativity or even creativity in general but also the fundamentals of cognition. By submitting the timeline and the standard mappings for spatialized time to considerable manipulation, in order to serve his aesthetic purposes, the Xenakis case study is also exposing the structure of these patterns, their possibilities, and their limits, in particular, how far the simulated interaction among material anchors can be taken while still retaining their major representational properties. Research on distributed cognition has indeed pointed at how a material or perceptual structure, such as a map or a computer interface, can help us to download cognitive effort, flagging this as a proof that cognition is distributed and situated, and therefore emerging from both the mind-brain-body and the interaction with the object and the environment. But we know little about the mental manipulations of these anchors, which may also take place without direct action or in the absence of the perceptual stimulus. We also need to know much more about the possibility of combining more than one anchor into a novel, more complex anchoring system, just like Xenakis did for *Psappha*.

Very much in the interdisciplinary spirit of Xenakis, who so often transferred ideas across music, architecture, mathematics, engineering, or computing, we can now go to other intellectual domains for comparison. This will allow us to shed light on both the general cognitive abilities and the specificities of musical creativity. If we create sufficient common ground, a "shared conceptual space," where musicology can engage with the general quest for human meaning-making in the cognitive sciences, we can expect the emergent design to render exciting results about both music and cognition, just like Xenakis' gearwheel-sieve interacts with the general timeline shared by all, giving us the unique rhythmical experience of *Psappha*.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. A-SB-C from the perspective of musicology and music theory, CP from the perspective of cognitive science, and JB from both sides.

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REFERENCES

Agon, C., Andreatta, M., Assayag, G., and Schaub, S. (2004). Formal aspects of Iannis Xenakis' 'symbolic music': a computer-aided exploration of compositional processes. *J. New Music Res.* 33, 145–159. doi: 10.1080/0929821042000310621

Anku, W. (2000). Circles and time: a theory of structure organization of rhythm in African music. *Music Theory Online* 6. Available at: https://mtosmt.org/issues/mto.00.6.1/mto.00.6.1.anku_frames.html (Accessed December 17, 2020).

Ariza, C. (2005). The Xenakis sieve as object: a new model and a complete implementation. *Comput. Music. J.* 29, 40–60. doi: 10.1162/0148926054094396

Barthel-Calvet, A.-S. (2000). Le rythme dans la pensée et l'œuvre de Iannis Xenakis. dissertation thesis. Paris: EHESS.

Barthel-Calvet, A.-S. (2001). "Temps et rythme chez Xenakis: le paradoxe de l'architecte" in *Portrait(s) de Iannis Xenakis*. ed. F.-B. Mâche (Paris: BNF), 159–170.

Barthel-Calvet, A.-S. (2003). Métastassis-analyse: Un texte inédit de Iannis Xenakis sur 'Metastasis'. *Rev. de Musicol.* 89, 129–187.

Barthel-Calvet, A.-S. (2009). De l'ubiquité poïétique dans l'oeuvre de Iannis Xenakis: Espace, temps, musique, architecture. *Intersections* 29, 9–51. doi: 10.7202/1000038ar

Barthel-Calvet, A.-S. (2011). Xenakis et le sérialisme: l'apport d'une analyse génétique de 'Metastasis'. *Intersections* 31, 3–21. doi: 10.7202/1013211ar

Barthel-Calvet, A.-S. (2012). L'archéologie d'un œuvre: analyse et présentation des carnets de jeunesse de se Xenakis. *Rev. de Musicol.* 98, 43–84.

Bays, C., and Hudson, R. H. (1977). The segmented sieve of Eratosthenes and primes in arithmetic progressions to 10^{12}. *BIT Numer. Math.* 17, 121–127. doi: 10.1007/BF01932283

Becker, J. (1980). *Traditional music in modern Java: Gamelan in a changing society*. Honolulu: The University Press of Hawaii.

Benadon, F. (2007). A circular plot of rhythm visualization and analysis. *Music Theory Online* 13. Available at: https://www.mtosmt.org/issues/mto.07.13.3/mto.07.13.3.benadon.html#locke_1996 (Accessed December 17, 2020).

Bertocchi, S. (2001). "'Xas' pour quatuor de saxophones" *in Presences of/Présences de Iannis Xenakis*. ed. M. Solomos (Paris: CDMC), 179–184.

Besada, J. L. (2018). "Sharing and enacting cognitive metaphors in musical distributed contexts: a case study form IRCAM" in *Proceedings of ICMPC15/ESCOM10*. eds. R. Parncutt and S. Sattmann. July 23–28, 2018 (Graz: University of Graz), 77–82.

Besada, J. L. (2019). "Where science-based music comes from: some cognitive remarks upon contemporary compositional practices inspired by mathematical concepts, operations, and objects" in *Twentieth-century music and mathematics*. ed. R. Illiano (Turnhout: Brepols), 261–277.

Besada, J. L. (2020). "Visualizing sound, hearing diagrams: on the creative process of 'Syrmos' by Iannis Xenakis" in *Diagrammatic Representation and Inference: 11th International Conference, Diagrams 2020*. eds. A.-V. Pietarinen, P. Chapman, L. B. Smet, V. Giardino, J. Corter and S. Linker. August 24–28, 2020 (Cham: Springer), 162–166.

Besada, J. L., and Pagán Cánovas, C. (2020). Timelines in spectral composition: a cognitive approach to musical creativity. *Organ. Sound* 25, 142–155. doi: 10.1017/S1355771820000059

Boden, M. A. (2009). Computer models of creativity. *AI Mag.* 30, 23–34. doi: 10.1609/aimag.v30i3.2254

Boroditsky, L., and Ramscar, M. (2002). The roles of body and mind in abstract thought. *Psychol. Sci.* 13, 185–189. doi: 10.1111/1467-9280.00434

Cheney, D., and Seyfarth, R. (1988). Assessment of meaning and the detection of unreliable signal by vervet monkeys. *Anim. Behav.* 36, 477–486. doi: 10.1016/S0003-3472(88)80018-6

Clarke, E., Doffman, M., and Lim, L. (2013). Distributed creativity and ecological dynamics: a case study of Liza Lim's 'Tongue of the Invisible'. *Music. Lett.* 94, 628–663. doi: 10.1093/ml/gct118

Cojocaru, A. C., and Murty, M. R. (2006). *An introduction to sieve methods and their applications*. Cambridge: Cambridge University Press.

Collins, D. (2005). A synthesis process model of creative thinking in music composition. *Psychol. Music* 33, 193–216. doi: 10.1177/0305735605050651

Coulson, S., and Pagán Cánovas, C. (2013). Understanding timelines: conceptual metaphor and conceptual integration. *Journal of Cognitive Semiotics* 5, 198–219. doi: 10.1515/cogsem.2013.5.12.198

DeLio, T. (1980). Iannis Xenakis' 'Nomos Alpha': the dialectics of structure and materials. *J. Music Theory* 24, 63–95. doi: 10.2307/843739

Donin, N. (2017). "Domesticating gesture: the collaborative process of Florence Baschet's 'Streicherkreis' for 'augmented' string quartet (2006–08)" in *Distributed creativity: Collaboration and improvisation in contemporary music*. eds. E. Clarke and M. Doffman (New York: Oxford University Press), 70–87.

Donin, N., and Féron, F. -X. (2012). Tracking the composer's cognition in the course of a creative process: Stefano Gervasoni and the beginning of 'Gramigna'. *Music. Sci.* 16, 262–285. doi: 10.1177/1029864912448328

Donin, N., and Theureau, J. (2006). Theoretical and methodological issues related to long term creative cognition: the case of musical composition. *Cogn. Technol. Work* 9, 233–251. doi: 10.1007/s10111-007-0082-z

Exarchos, D. (2007). "Injecting periodicities: sieves as timbres" in *Proceedings of the 3rd Sound and Music Computing Conference 2007*; July 11–13, 2007 (Lefkada: SMC), 68–74.

Exarchos, D. (2009). "The sieves of Iannis Xenakis" in *Mathematics and computation in music: MCM 2007*. eds. T. Klouche and T. Noll (Berlin and Heidelberg: Springer), 419–429.

Fauconnier, G. (1985). *Mental spaces: Aspects of meaning construction in natural language*. Cambridge: Cambridge University Press.

Fauconnier, G. (1997). *Mappings in thought and language*. Cambridge: Cambridge University Press.

Fauconnier, G., and Turner, M. (2002). *The way we think: Conceptual blending and the mind's hidden complexities*. New York: Basic Books.

Fauconnier, G., and Turner, M. (2008). "Rethinking metaphor" in *The Cambridge handbook of metaphor and thought*. ed. R. W. Gibbs (Cambridge: Cambridge University Press), 57–66.

Flint, E. R. (1993). Metabolae, arborescences and reconstruction of time in Iannis Xenakis's 'Psappha'. *Contemp. Music. Rev.* 7, 22–48. doi: 10.1080/07494469300640131

Flint, E. R. (2001). "The experience of time and 'Psappha'" in *Presences of/Présences de Iannis Xenakis*. ed. M. Solomos (Paris: CDMC), 163–171.

Fuhrman, O., and Boroditsky, L. (2010). Cross-cultural differences in mental representations of time: evidence from an implicit nonlinguistic task. *Cogn. Sci.* 34, 1430–1451. doi: 10.1111/j.1551-6709.2010.01105.x

Gibson, B. (2001). "Théorie de cribles" in *Presences of/Présences de Iannis Xenakis*. ed. M. Solomos (Paris: CDMC), 85–92.

Gibson, B. (2011). *The instrumental music of Iannis Xenakis: Theory, practice, self-borrowing*. Stuyvesant, NY: Pendragon Press.

Greaves, G. (2001). *Sieves in number theory*. Berlin and Heidelberg: Springer.

Halberstam, H., and Richert, H. -E. (1974). *Sieve methods*. London and New York: Academic Press.

Hoffmann, P. (2019). "My music makes no revolution: thoughts on the role of mathematics in the work of Iannis Xenakis" in *Twentieth-century music and mathematics*. ed. R. Illiano (Turnhout: Brepols), 41–60.

Hutchins, E. (2005). Material anchors for conceptual blends. *J. Pragmat.* 37, 1555–1577. doi: 10.1016/j.pragma.2004.06.008

Hutchins, E. (2011). "Enaction, imagination, and insight" in *Enaction: Towards a new paradigm for cognitive science*. eds. J. Stewart, O. Gapenne and E. A. D. Paolo (Cambridge, MA: The MIT Press), 425, 250.

Jones, B. W. (1964). *Modular arithmetic*. New York: Blaisdell.

Jones, E. (2001). Residue-class sets in the music of Iannis Xenakis: an analytical algorithm and a general intervallic expression. *Perspect. New Music* 39, 229–261.

Kiourtsoglou, E. (2017). An architect draws sound and light: new perspectives on Iannis Xenakis's 'Diatope' and 'La Légende d'Eer' (1978). *Comput. Music. J.* 41, 8–31. doi: 10.1162/COMJ_a_00437

Koestler, A. (1964). *The act of creation*. New York: Macmillan.

Koetting, J. (1970). Analysis and notation of west African drum ensemble music. *Selected Reports* 1, 115–147.

Kozak, M. (2020). *Enacting musical time: The bodily experience of new music*. New York: Oxford University Press.

Laeng, B., and Hofseth, A. (2019). Where are the months? Mental images of circular time in a large online sample. *Front. Psychol.* 10:2634. doi: 10.3389/fpsyg.2019.02634

Lakoff, G., and Nuñez, R. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York: Basic Books.

Lalitte, P. (2018). Autour de 'Psappha' et de 'Rebonds A'. [Conference presentation]. Interpréter/Performer Xenakis. [Saint-Denis]: Université Paris 8. Available at: http://www-artweb.univ-paris8.fr/?Interpreter-Performer-Xenakis-2334

London, J. (2004). *Hearing in time: Psychological aspects of musical meter*. New York: Oxford University Press.
Mithen, S. (1999). *The prehistory of the mind: The cognitive origins of art, religion and science*. *1st Edn.* London: Thames and Hudson.
Montuori, A., and Purser, R. E. (1995). Deconstructing the lone genius myth: toward a contextual view of creativity. *J. Humanist. Psychol.* 35, 69–112.
Nagy, Z. (2017). *Embodiment of musical creativity: The cognitive and performative causality of musical composition*. Abingdon and New York: Routledge.
Noll, T., Andreatta, M., Agon, C., and Amiot, E. (2006). "Computer-aided transformational analysis with tone sieves" in *Proceedings of the 2nd Sound and Music Computing Conference 2006*; May 18–20, 2006 (Marseille: SMC), 149–154.
Overton, W. F. (1994). The arrow of time and the cycle of time: concepts of change, cognition, and embodiment. *Psychol. Inq.* 5, 215–237. doi: 10.1207/s15327965pli0503_9
Pace, I. (2001). The harpsichord works of Iannis Xenakis. *Contemp. Music. Rev.* 20, 125–140. doi: 10.1080/07494460100640121
Pagán Cánovas, C., and Turner, M. (2016). "Generic integration templates for fictive communication" in *The conversation frame: Forms and functions of fictive interaction*. eds. E. Pascual and S. Sandler (Amsterdam and Philadelphia: John Benjamins), 45–62.
Pagán Cánovas, C., Valenzuela, J., and Santiago, J. (2015). Like the machete the snake: integration of topic and vehicle in poetry comprehension reveals meaning construction processes. *Psychol. Aesthet. Creat. Arts* 9, 385–393. doi: 10.1037/aca0000024
Peck, R. W. (2003). Toward an interpretation of 'Nomos alpha'. *Perspect. New Music* 41, 66–118.
Schiavio, A., Moran, N., van der Schyff, D., Biasutti, M., and Parncutt, R. (2020). Processes and experiences of creative cognition in seven Western classical composers. *Music. Sci.* doi: 10.1177/1029864920943931
Segre, M. (1994). Peano's axioms in their historical context. *Arch. Hist. Exact Sci.* 48, 201–342. doi: 10.1007/BF00375085
Small, C. (1998). *Musicking: The meaning of performing and listening*. Middletown, CT: Wesleyan University Press.
Solomos, M. (1997). Esquisses pré-compositionnelles et œuvre: les cribles de 'Nomos Alpha'. *Les Cahiers du CIREM* 40–41, 141–155.
Squibbs, R. (2000). "Musical composition as applied mathematics: set theory and probability in Iannis Xenakis's 'Herma'" in *Bridges: Mathematical Connections in Art, Music, and Science, Conference Proceedings 2000*; July 28–31, 2000 (London: Tarquin Group), 141–152.
Squibbs, R. (2002). Some observations on pitch, texture, and form in Xenakis' 'Mists'. *Contemp. Music. Rev.* 21, 91–108. doi: 10.1080/07494460216653
Squibbs, R. (2003). Xenakis in miniature: style and structure in 'à. r. (Hommage à Ravel)' for piano (1987). *Perspect. New Music* 41, 120–153.
Stewart, J., Gapenne, O., and Paolo, E. A. D. (eds.) (2011). *Enaction: Toward a new paradigm for cognitive science*. Cambridge, MA: The MIT Press.
Tipei, S. (1987). "Maiden voyages": a score produced with MP1. *Comput. Music. J.* 11, 49–56. doi: 10.2307/3680319
Tipei, S. (1989). The computer: a composer's collaborator. *Leonardo* 22, 189–195. doi: 10.2307/1575227
Toussaint, G. (2005). "The geometry of musical rhythm" in *Japanese Conference on Discrete and Computational Geometry*. eds. J. Akiyama, M. Kan and X. Tan. October 8–11, 2004 (Berlin and Heidelberg: Springer), 198–212.
Toussaint, G. (2013). *The geometry of musical rhythm: What makes a "good" rhythm good?* Boca Raton, NY: CRC Press.
Vandenbogaerde, F. (1968). Analyse de 'Nomos Alpha' de I. Xénakis. *Math. Sci. Hum*. 24, 35–50.
Vriend, J. (1981). 'Nomos Alpha' for violoncello solo (Xenakis 1966): analysis and comments. *Interface* 10, 15–82. doi: 10.1080/09298218108570328
Wannamaker, R. A. (2001). Structure and perception in 'Herma' by Iannis Xenakis. *Music Theory Online* 7. Available at: https://mtosmt.org/issues/mto.01.7.3/mto.01.7.3.wannamaker.html (Accessed December 17, 2020).
Weger, U. W., and Pratt, J. (2008). Time flies like an arrow: space-time compatibility effects suggest the use of a mental timeline. *Psychon. Bull. Rev.* 15, 426–430. doi: 10.3758/pbr.15.2.426
Weibel, P. (2020). "The road to UPIC: from graphic notation to graphic user interface" in *From Xenakis's UPIC to graphic notation today*. eds. P. Weibel, L. Brümmer and S. Kanach (Berlin: Hatje Cantz), 486–523.
Xenakis, I. (1956). Wahrscheinlichkeitstheorie und Musik. *Gravesaner Blätter* 6, 28–34.
Xenakis, I. (1963). *Musiques Formelles.* Revue Musicale, 253–254.
Xenakis, I. (1965). La voie de la recherche et de la question: formalisation et axiomatisation de la musique. *Preuves* 177, 33–36.
Xenakis, I. (1966). Zu einer Philosophie der Musik/towards a philosophy of music. *Gravesaner Blätter* 29, 23–38/39–52.
Xenakis, I. (1967). Vers une métamusique. *La Nef* 29, 120–129.
Xenakis, I. (1968). Vers une philosophie de la musique. *Revue d'Esthétique* 21, 173–210 [modified version of Xenakis, 1966].
Xenakis, I. (1988). Sur le temps. *Revue de l'Université de Bruxelles.* 1–2, 193–200.
Xenakis, I. (1990). Sieves. *Perspect. New Music* 28, 58–78.
Xenakis, I. (1992). *Formalized music: Thought and mathematics in composition*. Stuyvesant, NY: Pendragon Press.
Yamada, Y., and Kato, Y. (2006). Images of circular time and spiral repetition: the generative life cycle model. *Cult. Psychol.* 12, 143–160. doi: 10.1177/1354067X06064575
Zbikowski, L. (2019). "Cognitive extension and musical consciousness" in *Music and consciousness 2: Worlds, practices, modalities*. eds. R. Herbert, D. Clarke and E. Clarke (Oxford: Oxford University Press), 34–54.
Zembylas, T., and Niederauer, M. (2018). *Composing processes and artistic agency: Tacit knowledge in composing*. Abingdon and New York: Routledge.

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Evaluating Human-Computer Co-creative Processes in Music: A Case Study on the CHAMELEON Melodic Harmonizer

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CHAMELEON is a computational melodic harmonization assistant. It can harmonize a given melody according to a number of independent harmonic idioms or blends between idioms based on principles of conceptual blending theory. Thus, the system is capable of offering a wealth of possible solutions and viewpoints for melodic harmonization. This study investigates how human creativity may be influenced by the use of CHAMELEON in a melodic harmonization task. Professional and novice music composers participated in an experiment where they were asked to harmonize two similar melodies under two different conditions: one with and one without computational support. A control group harmonized both melodies without computational assistance. The influence of the system was examined both behaviorally, by comparing metrics of user-experience, and in terms of the properties of the artifacts (i.e., pitch class distribution and number of chord types characterizing each harmonization) that were created between the two experimental conditions. Results suggest that appreciation of the system was expertise-dependent (i.e., novices appreciated the computational support more than professionals). At the same time, users seemed to adopt more explorative strategies as a result of interaction with CHAMELEON based on the fact that the harmonizations created this way were more complex, diverse, and unexpected in comparison to the ones of the control group.

Keywords: creativity support tools, creativity evaluation, melodic harmonization, musical harmony, conceptual blending

1. INTRODUCTION

The desire to define and measure human creativity (e.g., Stein, 1953; Rhodes, 1961; Mooney, 1963; Boden et al., 2004; Wiggins et al., 2015) or even further to identify neural underpinnings of creative behaviors (e.g., Rosen et al., 2020; Boccia et al., 2015; Luft et al., 2018) has a long history in which music has had a prominent position (e.g., Johnson-Laird, 1988; Odena and Welch, 2009; Boccia et al., 2015; Rosen et al., 2020). Recent advances in artificial intelligence have made computational creativity a rapidly emerging scientific field. The general objective of this interdisciplinary research area is to obtain a deeper understanding and modeling of human creative processes in order to produce creative systems that can either exhibit creativity of their own, or assist humans in becoming more creative (e.g., Wiggins, 2006, 2008; Colton and Wiggins, 2012; Jordanous, 2012; Agres et al., 2016). This has, in turn, mandated the rigorous evaluation of artificial creativity which, like the evaluation of human creativity, poses a challenging problem.

Creative systems are usually evaluated either with respect to their end products (e.g., Ritchie, 2007) or the processes they employ to reach them (Colton, 2008). More recently some extra considerations were revisited as part of the older four Ps framework for creativity evaluation (Jordanous, 2016). According to the four Ps, the creative producer (i.e., the computer software or indeed the human programmer) and the press (i.e., the environment in which a creative act takes place) should also be added to the product and process criteria for a more comprehensive assessment of computational creativity. The evaluation of computational creativity in the arts becomes even more complex mainly due to the lack of a clear-cut metric for measuring success or failure. Unlike other fields of artificial intelligence (e.g., game-playing, computer vision, etc.), the generation of an aesthetic artifact does not have a strictly defined goal (such as winning a game of chess), thus making the assessment of its merit a rather challenging problem. Therefore, breaking down creativity into several—easier to assess—constituent dimensions such as novelty, divergence, value, problem solving ability, etc., constitutes a reasonable approach for the evaluation of creative systems (e.g., Jordanous, 2012).

At the same time, computational systems can be exploited as tools for enhancing human creativity in addition to being autonomous creative agents. In such a case, a computational system should be assessed in terms of the potential it offers for creativity support rather than its absolute creativity *per se*, i.e., the spotlight should be redirected from measuring how creative the actual system is, to measuring how it may enhance the creativity of a human user. The interest in the impact of technology on human creativity is more recent (Lubart, 2005; Shneiderman et al., 2006; Shneiderman, 2007) in comparison to research on the definition and evaluation of creativity itself (see, Cherry and Latulipe, 2014). However, creativity support has already been studied in the context of various creative human activities such as poetry writing (Kantosalo and Riihiaho, 2019), creative design (Albert and Runco, 1999; Bonnardel and Zenasni, 2010), 3D modeling (Chaudhuri and Koltun, 2010), or general problem solving (Massetti, 1996).

Artificially generated music is often limited to the level of style imitation, a task in which artificial intelligence methods become increasingly competent; this is achieved either by employing "traditional" rule-based methods (Ebcioğlu, 1988), Hidden Markov models (Allan and Williams, 2005; Raczyński et al., 2013) or, more recently, machine learning techniques based on artificial neural networks (see Briot et al., 2017). Successful style replication is considered in certain respects a creative task and advanced techniques have exhibited interesting results toward this direction (e.g., Hadjeres et al., 2017). However, departing from a given style into new unexplored musical territory has often a greater creative value. Attempts have been made to "interpolate" between, or even "extrapolate" from the learned material and generate music that either meaningfully crosses the borders of learned styles (e.g., Roberts et al., 2017), or applies stylistic aspects of one learned style to another (Brunner et al., 2018). The methods and approaches reviewed herein, are the most relevant to what CHAMELEON was designed and developed for. For a thorough review of the many methods and approaches that have been successfully applied to style-related music generation, the reader is referred to Kaliakatsos-Papakostas et al. (2020).

The focus of this paper is on the CHAMELEON[1] melodic harmonization assistant (Kaliakatsos-Papakostas et al., 2017), which follows a paradigm of computational creativity that not only extrapolates musical styles, but also generates fundamentally new harmonic material through hybrid methods that are based on generative implementations of Conceptual Blending (CB) and statistical learning. CB Theory has been examined as a fundamental tool that humans use to understand and generate new concepts (Fauconnier and Turner, 2003; Goguen, 2006), whereby two *input* conceptual spaces are combined to generate a new conceptual space. The new conceptual space commonly features new unforeseen properties that arise from the combination of elements and relations of the input spaces. CHAMELEON employs a generative algorithmic implementation of CB theory on chord transitions, where chords are represented by their General Chord Type (GCT, Cambouropoulos et al., 2014). The GCT incorporates an algorithm that first performs root finding on a chord and then it unrolls the hierarchy of the remaining pitch classes, identifying the basic components of this chord (i.e., third, fifth, seventh, and other extensions); we will be referring to these basic components as the "type" of the chord. Chord transitions in CHAMELEON (pairs of successive chords), are modeled as pairs of GCTs, along with information about the root motion of the involved chords (integer value between −5 and 6) and whether there is semitone motion (ascending or descending) to the root of the second chord (separate boolean values for ascending and descending). Training data of GCT transitions from diverse styles are fed into CHAMELEON which learns transition probabilities and can generate new melodic harmonizations from the learned styles using a Hidden Markov Model. Therefore, the transition probability matrix describes chord transitions, where chords are represented as GCTs.

The unique feature of CHAMELEON, however, is that it can augment the Markov transition tables of two learned idioms by blending the most common transitions of the two input idioms. The new, augmented transition probability table incorporates diagonally-adjacent copies of the initial transition matrices learned from the two idioms to be blended; it should be noted that the two learned idioms may include identical chords (e.g., the I or V^7 chords can be found both in the Bach Chorales and in Jazz), but in the augmented transitions matrix they are considered as separate chords. The, initially empty, two anti-diagonal blocks of the augmented transitions matrix are firstly filled with probability values belonging to transitions that are identical in both blended idioms (e.g., perfect cadences can be found both in Bach Chorales

[1]https://github.com/maximoskp/chameleon

and in Jazz). The probability value for each activated transition in the anti-diagonal blocks is the average of the two probabilities in the initial matrices. At a second stage, all pairs of the most common transitions on the initial idioms are blended (Eppe et al., 2015), giving rise to new chord transitions that might potentially incorporate new chords, in a sense that these chords do not belong to any of the learned idioms. Such chords are appended in the augmented matrix (a new line and a new column are added for any new chord), while the probability assigned to the transitions generated by blending is the average probability of the input transitions (for more information please refer to Kaliakatsos-Papakostas et al., 2017).

As a result, CHAMELEON can harmonize a given melody according to a number of different harmonic idioms or/and their harmonic blends[2]. This makes it capable of offering a variety of novel and unexpected "solutions" for melodic harmonization that could potentially influence human composers toward creating their own version.

From the above, it is evident that CHAMELEON can be regarded as both an autonomous computational creativity system and a creativity support system. While our previous work has investigated the former attribute of CHAMELEON by evaluating its creativity through its products (Zacharakis et al., 2018), the current work assesses CHAMELEON's performance as a creativity support tool in the domain of music. This requires a method capable of capturing a potential influence of the system on music creation by human users.

To this end, we devised an experiment to assess the way human users actively utilized the melodic harmonization assistant. Following a type of repeated-measures experimental design, one group of music students and one group of professional composers of contemporary music were initially asked simply to harmonize a given melody without any sort of influence. Subsequently, the same task was repeated on a very similar—but not the same—melody while giving participants the opportunity to interact with CHAMELEON. The aim of this evaluation was twofold: firstly to quantify user experience—also with respect to expertise—through a number of post-task questions assessing aspects related to creative behavior; and, secondly, to compare the outcome harmonizations between the two experimental conditions through computational extraction of harmonic features. The repeated-measures design was complemented by a between-groups comparison in which a different control group of novice participants performed the same two tasks but without computational support. This way, we were able to test for possible order effects in the characteristics of the produced harmonizations of the main experiment.

In order to be able to evaluate creativity in a meaningful way, a definition of this multifaceted concept is required. As discussed previously this is not a trivial problem. However, a common ground of many existing definitions is that creativity refers to a process that generates ideas or artifacts both novel (i.e., original or unexpected) and valuable (i.e., useful or appropriate) (for an overview please refer to Jordanous and Keller, 2016). This simple working definition of creativity is also adopted for the purposes of this study. Our basic hypothesis regarding the use of CHAMELEON is that it might stimulate the users toward producing more unconventional (i.e., novel) solutions compared to their initial harmonizations on very similar melodic material. It could then be argued that by creating something novel for themselves they will have manifested personal or psychological creativity (P-creativity) as defined by Boden et al. (2004). Besides, departure from the habitual thinking patterns that promotes originality has been widely deemed an important aspect of creative behavior (e.g., McCrae, 1987; Runco and Acar, 2012; Luft et al., 2018).

The assessment of whether such explorative behavior can indeed be recognized through the outcome harmonizations requires the ability to compare between different harmonic sequences of the same or very similar melodic material. While there exist a limited number of studies proposing metrics for chord distances and harmonic similarity (e.g., De Haas et al., 2008, 2010, 2011) the comparison between chord progressions is far from being a solved problem. This is particularly true for the case where harmonic progressions do not belong to standard common-practice tonal harmony (Lerdahl, 2004; Kostka and Payne, 2013). The comparison of chord sequences that belong to non-standard tonal styles or even belong to different non-tonal styles is a challenging task due to the difficulty of forming idiom-independent theories of harmony. To circumvent this problem three harmonic features (number of GCTs, number GCT types, and Pitch Class Profiles) that can either be used as descriptors of harmonic content or be transformed into general distance metrics between chord sequences in a style-independent manner were employed (see section 2.3). A preliminary analysis based on these metrics that was recently presented (Zacharakis et al., 2020) provided some evidence to support the basic hypothesis of increased harmonic diversity as a result of interaction with CHAMELEON.

The next section presents the details of the experiment, the behavioral creativity metrics used and the calculation of the harmonic features. The results section is separated into the analysis of the behavioral data and the analysis of the actual harmonizations generated by the participants. The discussion offers some perspective on the current findings and concludes by a brief reference to a compositional project that came as a byproduct of this laboratory experiment. In this project, a small subgroup of our participants were asked to compose short pieces for a string quartet that were inspired by their interaction with the system during the experiment. The pieces were presented in a live concert where each of the composers explained how they integrated ideas suggested by CHAMELEON in their compositional practice.

[2]CHAMELEON, as a basic melodic harmonization assistant, receives a melody as an input and suggests chord symbols for harmonizing this melody. It also generates actual chords that implement those chord symbols, but with rudimentary voice leading without expressional characteristics, i.e., vertical chords are placed whenever chords change. Therefore, CHAMELEON does not create actual arrangements as, for example, "Band In A Box," but it automatically fills in the chords to be played by an arrangement (e.g., preparing a chord chart for a "Band In A Box" song).

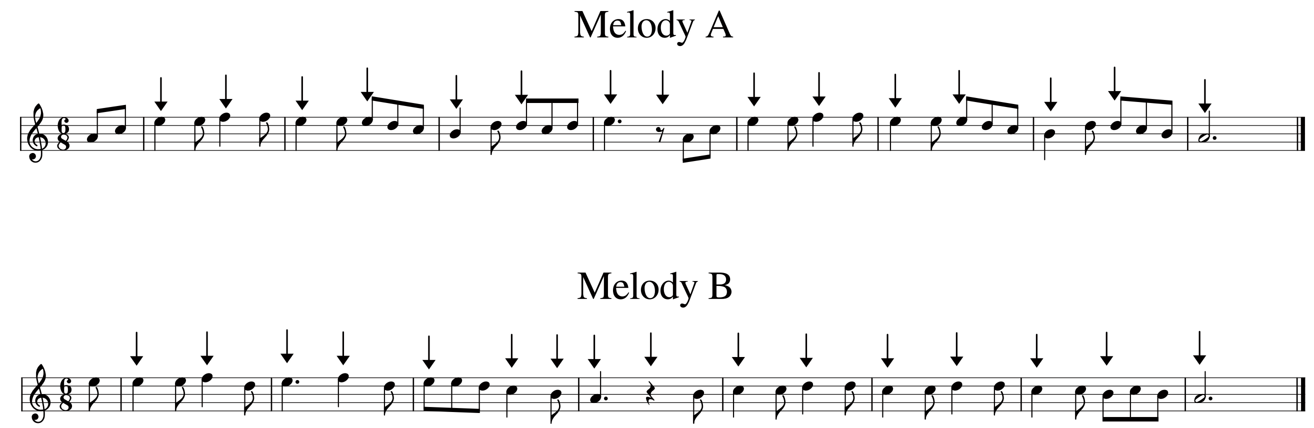

FIGURE 1 | The two melodies used in the harmonization task. The upper melody ("Menexedes kai Zoumboulia") was employed in the simple harmonization task whereas the lower one ("Lullaby from Southern Italy") was used for the computationally-supported harmonization. Arrows indicate the requested harmonic rhythm.

2. MATERIALS AND METHODS

2.1. Main Experiment

Twenty five participants that were either students from the School of Music Studies of the Aristotle University of Thessaloniki ($N = 20$, mean age = 23.2, std age = 5.8, 10 female) or professional contemporary music composers ($N = 5$, mean age = 32.6, std age = 11.1, 1 female) took part in the main experiment. The experimental procedure comprised two phases in a repeated-measures design. In phase one, participants were asked to harmonize the melody of a Greek traditional folk song called "Menexedes kai Zoumboulia" (melody A) in minor mode (see **Figure 1**). They were asked to place chords at the positions indicated by arrows (i.e., harmonic rhythm was fixed) and to use satisfaction of personal preference as the sole criterion for their harmonization, even at the cost of not conforming to standard harmonic rules. Voice leading was not at the center of this study, therefore participants were advised to omit it in order to save time.

In the second phase, participants were similarly asked to harmonize a melody of a folk lullaby from Southern Italy (melody B) also in minor mode (see **Figure 1**). An inspection of **Figure 1** reveals that the selected melodies of both phases were almost identical in rhythmic and harmonic features. The melodic lines were akin, the harmonic rhythms requested were almost the same and both featured very similar implied harmony (see **Supplementary Figure 1** for a presentation of the most typical harmonizations for these two melodies). The selection of these two closely related melodies served the purpose of requesting an equivalent but not identical task between the two experimental conditions. The directions regarding harmonic rhythm and voice leading were identical with phase one. This time, however, participants had additional access to CHAMELEON and they were prompted to explore its capability to offer various harmonizations on this particular melody. After giving a short demonstration of CHAMELEON, the experimenter made it clear that the extent to which participants should exploit the solutions offered by it for their own harmonizations would be totally up to them. It was particularly stressed that it would be fine even to ignore CHAMELEON's output completely.

Figure 2 shows the online CHAMELEON user interface that was provided to the participants. This interface allowed users to choose from the following eight harmonic idioms (styles) available in all modes for each idiom:

- Selection of 35 Bach chorales from the Breitkopf edition. This set represents baroque homophonic harmonic style (seventeenth-eighteenth century).
- Selection of jazz standards from the Real Book (melodies with chord symbols), mainstream jazz harmony.
- The dataset of the Kostka-Payne corpus (Kostka and Payne, 2013), produced by David Temperley (chord-list file) and Bryan Pardo (MIDI files with chords' quality). This set represents classical and romantic harmonic style (eighteenth-nineteenth century).
- Selected short excerpts of twentieth century whole-tone harmonization concepts from the textbooks of Stefan Kostka, Kent Williams, Walter Piston, and various other sources.
- Selection of 3-voice and 4-voice polyphonic songs from Epirus (transcriptions by K. Lolis), minor pentatonic harmony.
- Fauxbourdon excerpts or short pieces (thirteenth-fourteenth centuries, Dufay, Binchois, et al.).
- Selected modal homophonic chorales by Osiander, Praetorius, Scheidt, Hassler, Vulpius, Lasso, Walter, et al. Further categorization by mode is possible.
- Organum excerpts or short pieces (eleventh-twelfth centuries).

The participants had the additional option to blend two selected styles in different tonalities, as, for instance, blend C minor in Bach Chorale style with E major in the Jazz style (it is even possible to blend two different tonalities of the same style, e.g., blend C major with E♭ major in the Bach Chorale style). Two voice layout options were also offered: (a) root position implementation of chords (that made reading the output easier); and (b) a statistical learning-based method that learned and first applied bass voice leading (in case of blending the statistical models of the blended idioms were averaged) and then

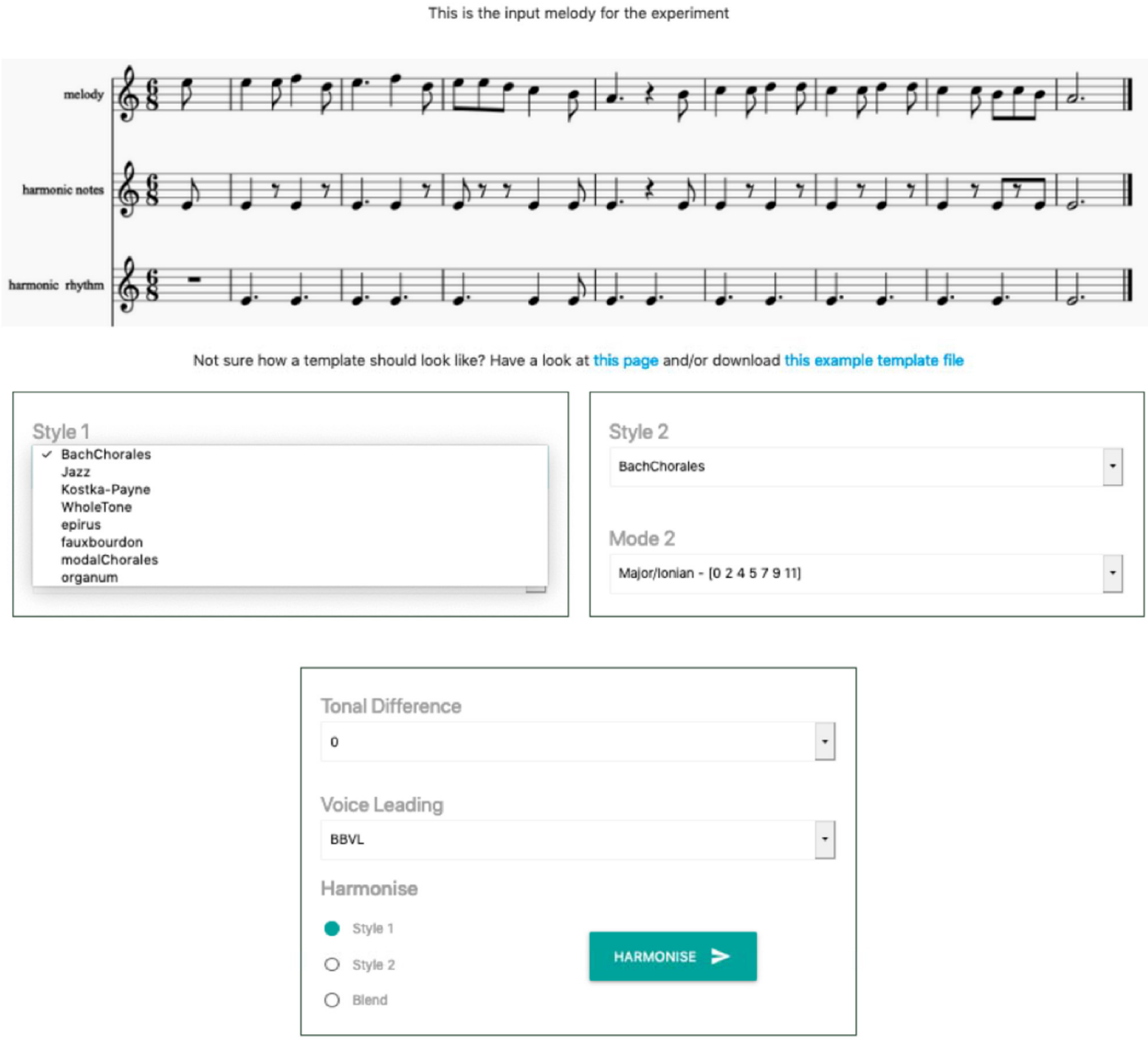

FIGURE 2 | The online CHAMELEON user interface. The melody for harmonization together with the requested harmonic rhythm (i.e., when chord changes should occur) and important harmonic notes (i.e., notes that CHAMELEON will prioritize over others when selecting suitable chords for the underlying melody) were shown at the top. The options for harmonization were provided below. The user could select from the available harmonic styles using a drop-down menu and use the radio button at the bottom to opt for either a single-idiom harmonization or a blend between two different idioms. Some harmonic styles include more than one harmonic mode that the user could chose from. In addition, there was the option to blend two selected styles in different tonalities using the tonal difference drop-down menu. Finally, the interface allowed users to select type of voice leading. If no voice leading was necessary the system output chords in root position. The other option performed a rudimentary voice leading in the bass voice and in the intermediate voices.

intermediate voices were placed in closed position under the melody. The voice leading method is based on Cambouropoulos (2015) and it employs a Hidden Markov Model for determining the bass voice leading given the current melodic motion, the previous position of the bass and an expected distance between bass and melody voices. Pressing the "harmonize" button revealed a basic notation-like representation of the requested harmonization and gave the options to play it back and download it in a MusicXML format.

In both experimental phases, participants filled in a 7-point Likert scale post-task questionnaire for user-experience evaluation whose questions represented the following metrics as defined by Kantosalo and Riihiaho (2019): Enjoyment, Expressivity, Outcome satisfaction, Ease of use, Collaboration, Ownership, Exploration, Immersion, and Productivity. **Table 1** presents the questions corresponding to each metric both for the simple harmonization and for the computationally assisted task. Notice that some metrics did not apply to the

TABLE 1 | Metrics (as general concepts) and corresponding questions for the post-task questionnaires.

Metric	Quest. no.	7 point likert statement	
		Simple harmonization	Computationally supported harmonization
Enjoyment	Q1	–	I would be interested to use CHAMELEON in the future
Expressiveness	Q2	The harmonization of a given melody gave me the opportunity to be creative	The use of CHAMELEON gave me the opportunity to be creative
	Q3	I was able to express my ideas	I was able to express my ideas
Outcome satisfaction	Q4	I am satisfied with my harmonization	I am satisfied with my harmonization
Ease of use	Q5	The process of harmonization was easy	The process of harmonization was easy
	Q6	–	The use of CHAMELEON was easily comprehensible
Collaboration	Q7	–	CHAMELEON provided me with some good ideas
	Q8	–	CHAMELEON provided me with some good solutions that I could not have reached myself
Ownership	Q9	I feel that the harmonization belongs to me 100%	I feel that the harmonization belongs to me 100%
Exploration	Q10	–	The contact with CHAMELEON offered me a different harmonization perspective
Immersion	Q11	I was able to maintain concentration on my task	The use of CHAMELEON helped me maintain concentration on my task
Productivity	Q12	I was productive	CHAMELEON affected my productivity positively
Free-answer questions		–	What did you like the most about CHAMELEON?
		–	What did you like the least about CHAMELEON?
		–	If you had the opportunity which of the system's capabilities would you redesign?
		–	What are your thoughts regarding computationally assisted music composition after this experience?

simple harmonization task and were therefore not used. In addition, four free-answer questions concluded the questionnaire of the computationally-assisted harmonization (second phase). Apart from filling in the post-task questionnaires, participants submitted their melodic harmonization for each phase. For the computationally-assisted harmonization task they were given the option to submit up to four example harmonizations produced by CHAMELEON which had attracted their interest or even potentially influenced their own harmonization.

2.2. Control Experiment

The presentation order of the tasks in the main experiment remained fixed since the simple harmonization experience of melody A was viewed as a reference for the user-experience evaluation of the computationally supported harmonization of melody B. Therefore, a possible order effect needed to be taken into account for the analysis of extracted harmonic features (see section 2.3). To this end, a complementary control experiment was conducted whereby the two harmonizations were performed in the same fixed order (melody A first, followed by melody B) but without computational support for the second task. Twenty two students from the School of Music Studies of the Aristotle University of Thessaloniki ($N = 22$, mean age = 20.3, std age = 5, 12 female) took part in the control experiment. The directions were identical to the main experiment but participants were not asked to fill in questionnaires for user-experience evaluation. Only the two produced harmonizations were acquired. This design examines whether potential differences in the characteristics of the harmonizations acquired through the two experimental conditions could be attributed to the treatment (i.e., computational support) or resulted from other factors.

These experiments were certified for ethical compliance by the research ethics board of the Aristotle University of Thessaloniki (Ref. number 66117/2020).

2.3. Calculation of Harmonic Features

The subjective user experience evaluation was complemented by a more objective assessment of harmonization characteristics based on computational extraction of harmonic features. Given that participants were free to use any type of harmonic palette, thus potentially avoiding tonal harmonic devices, harmonic content had to be captured using idiom-independent features of harmonic plurality. To this end, three different features based on the General Chord Type (GCT) (De Haas et al., 2008), the isolated type component of GCTs (without root information) and the Pitch Class Profiles (PCPs) were extracted from each harmonization. The plurality of harmonic content within a harmonization was quantified through the absolute number of GCT chords (unique root-type components) and chord types (isolated type component of the GCT). The PCP is the 12-dimensional vector that describes the percentages of pitch classes in the entire harmonization (harmonic part without the melody). To obtain the complexity of a harmonization based on its PCP, the Shannon Information Entropy (SIE) of this distribution was computed, allowing the representation of any harmonization complexity through a single numerical value

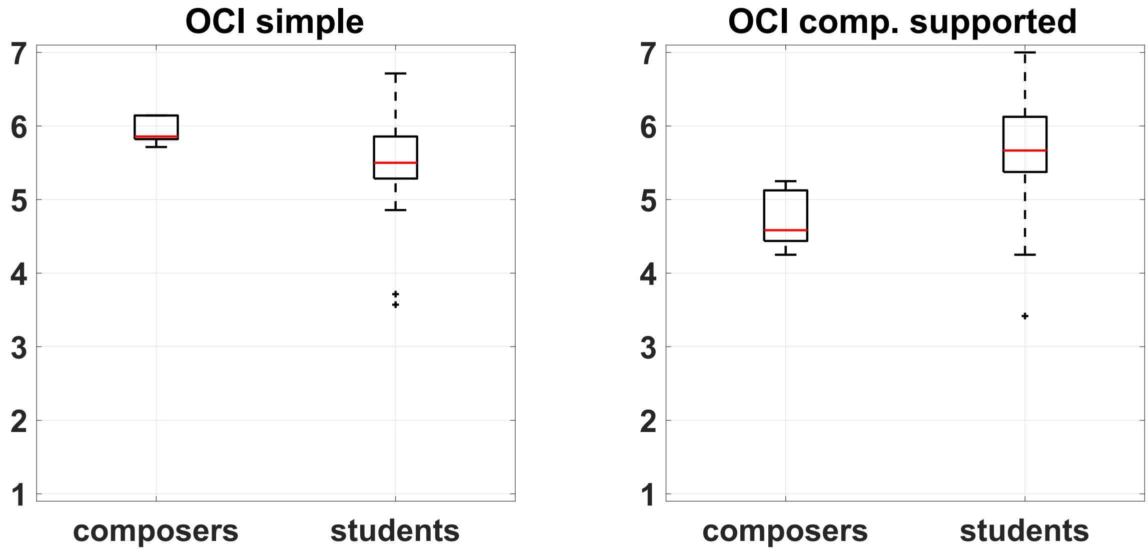

FIGURE 3 | Boxplots of the Overall Creativity Index (OCI) in the two experimental conditions for both participant groups. Mean OCI simple for composers = 5.8, Mean OCI simple for students = 5.57, mean OCI comp. supported for composers = 4.7, mean OCI comp. supported for students = 5.6.

(Kaliakatsos-Papakostas et al., 2010); the following formula is employed: $\text{SIE} = -\sum_p \text{PCP}(p)\ \log[\text{PCP}(p)]$, where PCP(p) is the distribution value for pitch class p. Greater SIE values indicate PCP distributions that are more uniform, which, in turn, indicates a richer variety of pitch content in the harmonization. Therefore, each harmonization was described by these three values, for each of which higher values indicated more complex harmonizations.

Apart from capturing complexity we were also interested in quantifying the diversity of the harmonizations obtained for each experimental condition together with their deviance from typicality. A prerequisite for this was the ability to calculate distances between harmonizations. The feature values were used to estimate such distances between harmonizations (see numbered list below) which were subsequently compared between conditions. These distances were also exploited to construct geometric representations of the harmonizations through Multidimensional Scaling Analysis (MDS). Specifically, distance metrics between harmonization 1 (*h1*) and harmonization 2 (*h2*) were devised as follows:

1. Common GCTs: the number of non-common GCTs employed in *h1* and *h2* over the number of total unique GCTs in *h1* and *h2*. In other words, this metric shows how many non-common chord labels are used in the two harmonizations; the larger the number, the higher the dissimilarity.
2. Common chord types: as above but restricted to the type component of the GCTs (regardless of root). This metric incorporates the types or "qualities" of the chord labels—e.g., in jazz guitar-style chord notations, how many non-common X7 or Xm7 are included in the harmonizations under comparison.
3. PCP distance: 1 minus the correlation of the (12-dimensional) PCP vectors (distribution of pitch classes throughout the entire harmonization) extracted from *h1* and *h2*. Since the compared melodies are transposed to the same key, PCP vectors are unbiased in terms of tonality. This metric indicates the similarity of the overall harmonic content between two harmonizations. PCP information has proven efficient for categorizing music according to style (Kaliakatsos-Papakostas et al., 2010).

3. RESULTS

3.1. Fixed Creativity Metrics

3.1.1. Assessment of the Overall Influence on Creativity for Composers and Students

The data of the post-task questionnaires were initially used to provide an indication of the overall creativity support offered by CHAMELEON as assessed by the two participant groups (students and composers). This was quantified by a metric that we refer to as the Overall Creativity Index (OCI) which was estimated as the average score of all the post-task questions for each participant. **Figure 3** shows the OCI boxplots between composers and students for the two experimental conditions. Since the OCI is derived from averaging ordinal data (i.e., ratings on Likert scales), the comparison of the OCI between the two groups was made through the non-parametric Wilcoxon rank-sum test. Results showed that means do not differ significantly ($z = -2, p = 0.051$) between the two groups in the simple harmonization, albeit the p-value is marginally above the 0.05 threshold. On the other hand, there is a significant difference ($z = 2.31, p = 0.042$, effect size $= 0.33$, median difference $= 1.08$) in the computationally supported case. This constitutes a reversal of the picture between the two conditions. Indeed, in the simple harmonization composers featured a higher OCI (even though marginally not significant enough), but in the

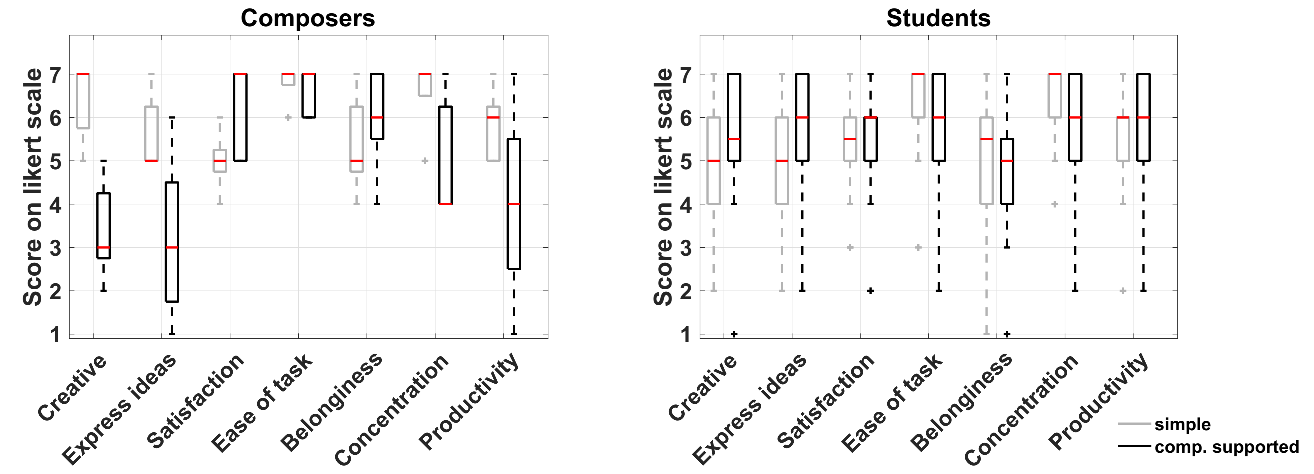

FIGURE 4 | Boxplots of the seven common questions between the two experimental conditions for composers and students.

TABLE 2 | Statistically significant differences that resulted from the Wilcoxon signed-rank test between the responses of the two experimental conditions for the students' group.

Question	*z*	*p*-value	Effect size	Median difference
Express ideas	−2.2	0.028	−0.35	−1
Ease of task	2.3	0.023	0.37	1
Concentration	2.6	<0.01	0.41	1

No statistically significant differences were identified for the composers' group.
Effect size: ($r = \frac{z}{\sqrt{N}}$).

computationally supported task their OCI declined substantially and was significantly lower than the corresponding OCI of students. It should be noted that the two conditions are not directly comparable at the general level due to the different number of questions involved in each post-task evaluation. These results already indicate an overall trend in the assessment of CHAMELEON between groups of participants and the following subsections will examine which specific questions are responsible for this general picture.

3.1.2. Comparison Between Experimental Conditions for Each Group

Figure 4 shows the box plot for the responses to the seven common questions between the two experimental conditions for the two participant groups separately. Again, a non-parametric approach was adopted for the comparison of the medians due to the ordinal nature of the data. The small sample size of the composers' group prevented the identification of significant differences in any of the questions, although some of the differences observed in the medians between the two conditions are quite large but still not necessarily significant. On the other hand, the students' group featured significant differences in three instances as shown in **Table 2**. Based on the results of the Wilcoxon signed-rank test, they felt it was easier to express their ideas when supported by CHAMELEON but at the same time this task was regarded as more difficult and it was harder for them to maintain concentration while using CHAMELEON. At this point, it has to be noted that effects in this study will not be corrected for multiple comparisons. If the level of significance was reduced to $p/7$ in this case (taking into account the 7 paired comparisons) according to a Bonferroni correction, then no effects would be identified. However, such an approach would increase the probability of falling into a type II error and rejecting an existing effect. According to the guidelines by Armstrong (2014) regarding the appropriate use of the Bonferroni correction, a study that includes only a small number of planned comparisons should not correct for multiple statistical testing. Since our study satisfies this condition, all current results will be reported at the significance level of $p < 0.05$.

3.1.3. Comparison Between Groups on Each Task

The responses did not pass the Shapiro-Wilk test for normality and as a result a non-parametric approach for median comparison was followed. Only one statistically significant difference was identified for the simple harmonization task and this was on the statement: "The harmonization of a given melody gave me the opportunity to be creative" with which composers agree more (Wilcoxon rank-sum test: $z = -2.2, p = 0.03$, effect size $= 0.44$, median difference $= -2$). On the contrary, the computationally supported condition featured a number of statistically significant differences. **Table 3** shows the statistically significant differences that resulted from the Wilcoxon rank-sum test between the two groups for the computationally supported task and **Figure 5** presents the respective boxplots. These differences indicate that the use of CHAMELEON resulted in higher enjoyment, higher capability of expressiveness and stronger collaboration with the system for the students' group than for the composers' group.

3.2. Free Text Evaluation

Participants also provided free-text answers to four post-task questions regarding CHAMELEON's use. **Table 4** summarizes opinions expressed by the two groups. The free-text responses showed that harmonic blending was the most appreciated system capability whereas the problematic score visualization with mistakenly spelled enharmonic notes and many ledger lines was identified as the major weakness. In addition, some participants would like to have been offered a greater variety of harmonic idioms and more convincing harmonizations in some styles. With regard to their thoughts on computationally supported music composition, the majority of the students mentioned that a computational assistant can potentially offer new ideas, promote productivity and increase creativity. However, some of them were not very keen on embracing its use stating that music creation should be exclusively a human endeavor. Additionally, a couple of composers expressed the opinion that computational assistance is more suited for amateur musicians.

TABLE 3 | Results of the Wilcoxon rank-sum test between the two groups for the computationally supported task.

Question	*z*	*p*-value	Effect size	Median difference
Future use	2.6	<0.01	0.37	2
Creative	2.6	<0.01	0.37	2.5
Express ideas	2.4	0.01	0.34	3
Good ideas	2.6	<0.01	0.37	2
Solutions	2.9	<0.01	0.41	3

Effect size: ($r = \frac{z}{\sqrt{N}}$).

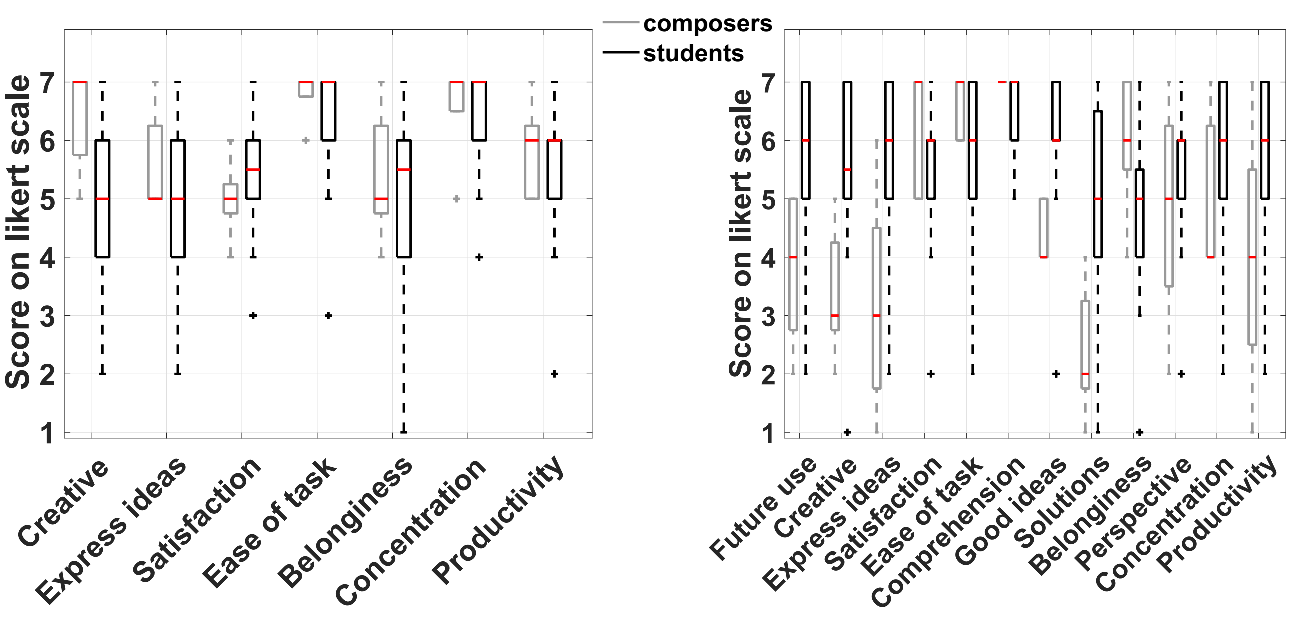

FIGURE 5 | Boxplots of the responses on each task between groups of participants.

TABLE 4 | Summary of the free text answers provided by the participants to the four post-task questions regarding the computationally supported task.

Group	Questions			
	What did you like the most about CHAMELEON?	**What did you like the least about CHAMELEON?**	**What feature of CHAMELEON would you redesign if you had the opportunity?**	**What are your thoughts regarding computational support in music composition after this experience?**
Composers	The capability of harmonic blending (3), the playback possibility	The lack of voice leading (2), the visualization of the produced score (2)	Some of the harmonic idioms which are not very convincing style-wise (2), more harmonic styles and scales (2)	Mostly for amateurs (2), can save time and provide ideas, computer creates the possibilities among which a composer can select
Students	The capability of harmonic blending (8), diverse solutions (5), ease of use-speed-playback (4), gives you ideas (3), saves you time	The visualization of the produced score was hard to read (7), the limited harmonic idioms available (5), the resulting harmonizations (4)	Increase the available harmonic idioms (6), make scores easier to read (3), include harmonic (2) analysis	Can give rise to new ideas (8), can increase productivity (5), can promote creativity (3), music composition should be an exclusively human endeavor (4), useful up to a point (3)

Numbers in parentheses indicate the number of participants that provided a similar answer.

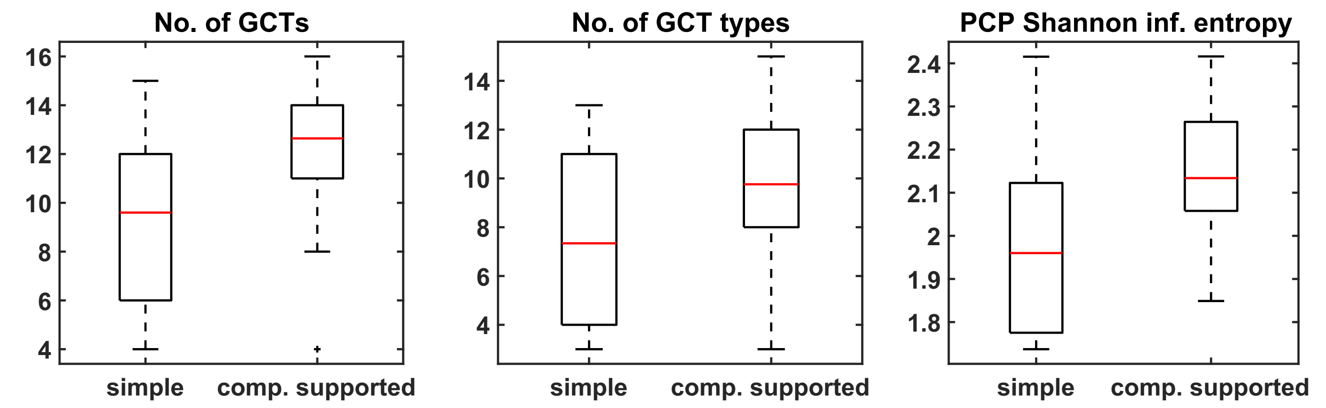

FIGURE 6 | Boxplots of the three harmonic features for both the simple and the computationally supported task.

TABLE 5 | Within and between group comparisons of the harmonizations obtained from the main and the control experiment based on three different harmonic features.

		Computational support (within group)				Control (within group)				Distance vectors (between groups)			
	Metric	*z*	*p*-value	Effect size	Median diff. A-B	*z*	*p*-value	Effect size	Median diff. A-B	*z*	*p*-value	Effect size	Median diff. A-B
Complexity	GCTs	−3.68	**<.001**	−0.52	−3	−2.12	**0.017**	−0.32	−1	−1.85	**0.032**	−0.27	−1
	GCT types	−2.94	**0.002**	−0.41	−2.4	−1.13	0.13	−0.17	−1	−1.86	**0.031**	−0.27	−2
	SIE of PCP	−3.83	<**0.001**	−0.54	−0.17	−1.36	0.086	−0.20	−0.06	−2.99	**0.003**	−0.44	−0.12
Diversity	GCTs	−6.85	<**0.001**	−0.28	−0.01	−2.85	**0.002**	−0.13	0	−2.76	**0.003**	−0.12	−0.0023
	GCT types	−2.92	**0.002**	−0.12	0	−2.16	**0.015**	−0.10	−0.02	−1.4	0.076	−0.061	−0.0208
	SIE of PCP	−4.46	<**0.001**	−0.18	−0.03	2.26	0.99	0.10	0.01	−5.77	<**0.001**	−0.25	−0.0408
Unexpectedness	GCTs	−2.64	**0.004**	−0.37	−0.03	−1.5	0.066	−0.23	−0.03	−5.86	<**0.001**	−0.85	−0.94
	GCT types	−1.83	**0.034**	−0.26	−0.05	−1.31	0.096	−0.20	−0.02	−5.86	<**0.001**	−0.85	−0.91
	SIE of PCP	−1.67	**0.047**	−0.24	−0.01	−0.027	0.393	−0.04	0.01	−5.85	<**0.001**	−0.85	−0.61

Wilcoxon signed-rank tests were employed to compare melodic harmonizations A and B for harmonic complexity, diversity, and unexpectedness (for definitions of these concepts please see the text) within each experimental group (main and control). Wilcoxon rank-sum tests were employed to directly compare between the independent experiments utilizing a vector of distances between harmonizations of melodies A and B (based on the harmonic features). The p-values in bold represent statistically significant effects at the level of 0.05.
Effect size: $(r = \frac{z}{\sqrt{N}})$.

3.3. Comparison Between Harmonizations of the Main and the Control Experiment

The previous section dealt with evaluating user experience of the computationally supported harmonization. This section will compare the produced harmonizations between the main and the control experiment utilizing the harmonic features described in section 2.3.

3.3.1. Comparison of Complexity

All three harmonic features (number of GCTs, number of GCT types, and PCP) that were calculated indicate an increase in the harmonic complexity of harmonizations when musicians are computationally assisted by CHAMELEON in comparison to the simple harmonization task. **Figure 6** shows that the number of GCTs as well as the number of GCT types were higher in the second task. The SIE of the PCP was also higher, indicating a flatter distribution of pitch classes in the second task. The medians of all metrics for the main experiment (computational support) are significantly greater compared to the control group (at significance level $p < 0.05$), as shown in **Table 5** that presents the results of the Wilcoxon sign-rank tests. At the same time, for the control experiment, only the number of GCTs is significantly increased in the second condition but with a comparatively smaller effect size (−0.32 to −0.52). To make between group comparisons, we calculated distance vectors by taking the difference of each feature between the two experimental conditions (e.g., number of GCTs in the harmonization of melody A - number of GCTs in the harmonization of melody B). These vectors were subjected to Wilcoxon rank-sum tests for independent samples which showed that the differences were significantly greater for the main experiment in comparison to the control experiment for all metrics of harmonic complexity.

3.3.2. Comparison of Diversity

The higher values in the harmonization metrics reported above are an indication of increased complexity of the harmonizations produced with the assistance of CHAMELEON. We further calculated the distances between harmonizations based on these

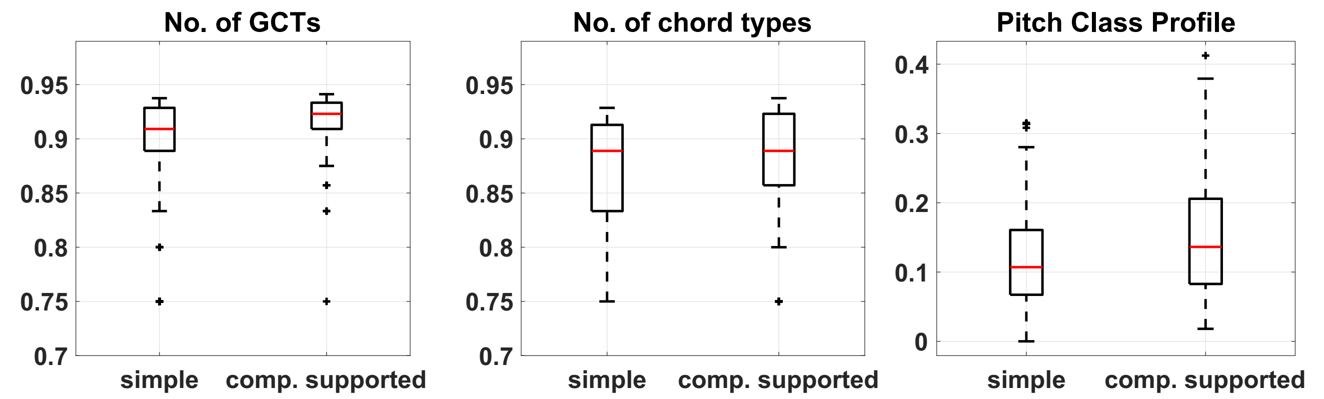

FIGURE 7 | Boxplots of the differences between harmonizations calculated based on the three features for the two conditions of the experiment. Median difference in No. of GCTs = −0.014, No. of chord types = 0, and Pitch Class Profiles = −0.029.

metrics to assess a potential difference in the divergence of the outcomes between the two experimental conditions. The distances between harmonizations were calculated as described in section 2.3.

The vectors of distances for all metrics did not pass the Shapiro-Wilk test for normality and therefore their medians were compared using the non-parametric Wilcoxon rank-sum test. All comparisons were significantly lower (at the $p = 0.05$ level) for the simple harmonization task compared to the computationally supported one, thus indicating that the outcomes of the second condition were less homogeneous. **Figure 7** shows the boxplots of the distances among harmonizations based on the three features. Again, **Table 5** shows that the computationally supported condition features significantly greater medians on all metrics (at the $p = 0.05$ level) according to the Wilcoxon sign-rank tests. In this case, however, the control experiment also features higher medians in two out of the three metrics, although with smaller effect size for the number of GCTs. The direct comparison between groups shows that larger diversity of produced harmonizations may be supported only based on the number of GCTs and the SIE of the PCPs, and not on the number of GCT types.

3.3.3. Comparison of Unexpectedness

To measure the degree of departure from the most expected harmonic solutions we asked a professor of music theory to create the most typical harmonizations as implied by each of the two melodies. These harmonizations are presented in the **Supplementary Material**. Subsequently, the distances between each of these two reference harmonizations and the corresponding participants' solutions were calculated based upon each of the three harmonic features and the distributions of the two vector distances were compared. A Wilcoxon rank-sum test was performed for each of the three feature-based distance pairs because all of them failed to pass the Shapiro-Wilk test for normality. These tests showed that in all three cases, the median of the distances between the harmonizations created by the participants and the corresponding most expected (implied) harmonization was significantly higher in the case of computational support than in the unsupported case. This indicates that, on average, participants were moving further away from the most typical harmonic solution when interacting with CHAMELEON in comparison to when harmonizing on their own. **Figure 8** shows the boxplots of the distances between harmonizations for each condition and the corresponding typical solution. Such differences were not observed in the control experiment in any of the metrics. In addition, the direct between-groups comparison showed that participants in the main experiment were drawn further away from the most typical harmonizations in comparison to the control group.

The above is also evident from **Figure 9** that presents the spatial configurations of the relationships between all the harmonizations based on the three different harmonic features (number of GCTs, number of GCT types, and PCP). The two-dimensional spatial configurations were calculated through a non-metric Multidimensional Scaling (MDS) analysis. It has to be noted that, for the number of GCTs and GCT types, the MDS model was very good for two dimensions (Stress1 = 0.08 and 0.13, respectively) whereas the model for PCP was poor (Stress1 = 0.30). Stress1 is a measure of misfit where a lower value indicates a better fit between actual and estimated distances (with a minimum of zero). One has to bear in mind that the relationships between harmonizations in these figures are represented by a mere two-dimensional model approximating the actual distances calculated by the harmonic features. However, it is clear from these representations that the two implied harmonizations are very similar to each other and that the simple harmonizations (white circles) tend to cluster closer to them than the computationally supported ones (black triangles). This is less prominent in the PCP-calculated distances, where the model is the least adequate for two dimensions.

4. DISCUSSION

The experiment presented in this paper aimed to study the potential influence of a creativity support tool in music composition. The analysis of both behavioral metrics of creativity and computationally extracted descriptive features of

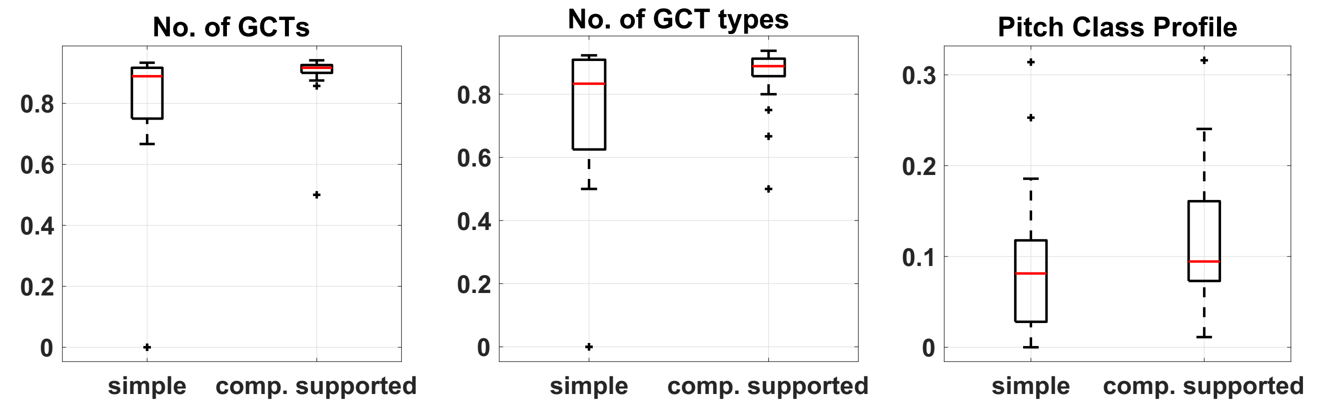

FIGURE 8 | Boxplots of the differences between harmonizations and the typical solution calculated based on the three features for the two conditions of the experiment. Median difference in No. of GCTs = −0.028, No. of chord types = −0.056, and Pitch Class Profiles = −0.013.

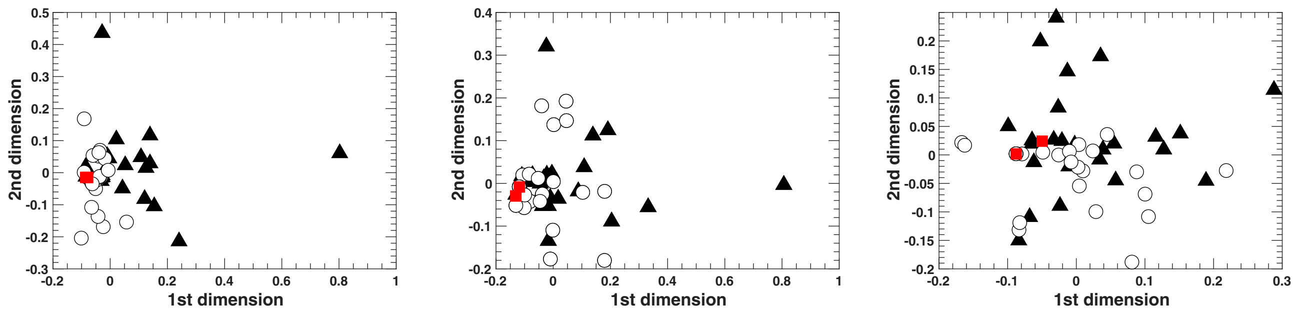

FIGURE 9 | Two-dimensional spatial configurations from Multidimensional Scaling on the distances based on **(left)** the number of GCTs, **(middle)** the number of GCT types, **(right)** the pitch class profiles. The red squares represent the implied harmonizations for the two melodies, the white circles represent the 25 simple harmonizations and the black triangles represent the 25 harmonizations that resulted from the computationally supported task.

the obtained harmonizations revealed some interesting findings regarding the use of CHAMELEON by the participants in this study. The general picture is that students seemed to appreciate the use of this tool more in comparison to professional composers based on the behavioral responses (see **Figure 3** and **Table 3**). More specifically, students appreciated CHAMELEON's assistance in expressing their ideas better despite finding it more cognitively demanding (see **Table 2**) compared to the simple harmonization. This did not prevent them from being significantly more favorable than composers regarding the future use of the tool (see **Table 3**).

The free-text responses indicated that the harmonic blending capability of CHAMELEON was appreciated by the participants but also highlighted that the visualization of the score was considered very primitive and thus requires re-designing. Interestingly, the views of participants on computationally supported creativity based on this particular experience varied. It was quite evident that the sophistication of the system did not match the sophistication possessed by professional composers on a melodic harmonization task and as a result they were not really impressed by its use. On the contrary, a large number of students seemed a lot more enthusiastic regarding the prospect of computational support in music creation based on their experience. Of course, free responses varied even within the student group probably reflecting different levels of expertise in melodic harmonization and even different levels of biases regarding the use of computational tools as creative assistants in music making.

The fixed-scale and free questionnaires measured aspects of how the system was perceived by its users and helped us identify features that were deemed stronger or weaker. Additionally, the computational analysis of the harmonizations complemented the picture of the behavioral data since this analysis did not involve the subjective judgement of the users. Harmonizations before and after computational support were quantitatively compared in terms of three concepts that usually appear in creativity evaluation literature: *complexity*, *diversity*, and *unexpectedness*. These comparisons revealed statistically significant differences between the two conditions of the main experiment. Computationally assisted harmonizations were more complex and unexpected overall in addition to forming a more diverse group.

To ensure that the effects identified from the main experiment should be attributed to the influence of CHAMELEON and not to the mere repetition of a similar task we examined the above findings in comparison with the corresponding ones from the control experiment. In all cases (with the exception of the metric number of GCT types for diversity) all kinds of comparisons between the control and the main experiment showed that the differences in harmonic complexity, diversity, and unexpectedness were greater for the main experiment compared to the control experiment. In other words, the increase of complexity, diversity, and unexpectedness observed in the computationally supported condition cannot be fully accounted for by the mere repetition of the task and should indeed be attributed—in some cases fully, in some partially—to the interaction with CHAMELEON.

These results show that a system for computational support had a clear and quantifiable influence on the harmonizations created by human users. The question that arises is whether this observation could suggest an increase in the creativity of the users. The mere increase in complexity that was observed in the computationally supported artifacts is not sufficient to justify such a claim as the relationship between perceived value and complexity is not linear but is best modeled through the bell-shaped Wundt curve (Heyduk, 1975). This means that when it comes to complexity there exists an optimal level that leads to the highest appreciation. However, we asked our participants to submit their harmonizations based solely on satisfaction of their personal preference (even at the cost of ignoring completely all the suggestions provided by CHAMELEON). This way it was ensured that the computationally supported harmonization would possess at least equal aesthetic value compared to the unsupported one as judged by their creator. Indeed, it is reasonable to assume that the computationally supported harmonization—which was always created last—could not have been deemed inferior to the simple one, given that participants were absolutely free to stick to their initial harmonic solution. That is, if participants chose to substantially alter their first approach this should indicate that they favored the altered version equally (if not more). According to our working definition of creativity presented in the introduction, the above rationale essentially transforms the evaluation of creativity to an assessment of novelty with respect to the produced artifacts. The fact that the computationally supported harmonizations featured higher complexity, higher originality and constituted a more diverse group compared to the unsupported ones implies that at least some users must have exhibited some form of P-creativity (i.e., they produced something that was novel for themselves but not necessarily novel to the world). This is also supported by the behavioral ratings on the statement: CHAMELEON provided me with some solutions that "I could not have reached myself" that received a median value of five out of seven in the students group.

At this point, it is important to note that based on this experimental design it is hard to argue that computational support actually increased the creativity of the process (i.e., the manner by which users reached solutions). Furthermore, the press/environment and producer components of the four Ps framework (Jordanous, 2016) were deemed constant in our case and were thus not considered at all. However, the presented evidence indicates that computational support can potentially affect the properties of the products by transfusing characteristics from which humans tend to extrapolate higher (perceived) creativity. All things considered, this study revealed that computational support inspired some users to be more adventurous and explore new harmonic spaces away from the most obvious harmonic solutions. At the same time, it should be acknowledged that this evidence stems from a case study with certain characteristics, the most notable of which is the fact that the requested task was deliberately chosen to be very simple. The selected melodies for harmonization featured strongly implied, simple harmonies in both experimental conditions and the implicit research question was: "can an otherwise simple harmonization task be affected by the suggestions of a melodic harmonization assistant?" It may be assumed that had the task been more complex and with higher degrees of freedom to begin with, (i.e., loosely implied harmony and high melodic chromaticism) the influence of computational support would have been less pronounced as users would tend to produce more complex and unexpected outcomes even without computational support. Different scenarios should also be examined in future work to obtain a more comprehensive perspective regarding the influence of CHAMELEON in melodic harmonization.

The experiments presented in this paper attempted to simulate natural conditions of music making as much as possible; however, it could not avoid certain restrictions in order to maintain a controlled experimental procedure, such as strict guidelines regarding harmonic rhythm and texture. As an additional qualitative exploration of the use of CHAMELEON, a further project was encouraged in the domain of free, unrestricted compositional practice. Six of our participants with varying levels of compositional experience volunteered to create musical vignettes for a string quartet inspired by our experiment. They used the melody of the "Lullaby from Southern Italy" (melody B) as primary material and drew upon harmonic information produced by CHAMELEON. These original works were presented in a concert in which the composers explained to the audience how they employed the creativity support system in their work. The creative exploitation of ideas and concepts suggested by CHAMELEON was evident in each of the short compositions and two indicative examples are presented below.

One of the composers created five short variations each named after one CHAMELEON harmonic blend, namely: I. Bach chorales & Organum; II. Whole Tone & Kostka-Pane; III. Epirus & Jazz; IV. Kostka-Pane & Jazz; V. Modal chorales & Kostka-Pane; thus indicating the harmonic influence from each one of these blends. The first four measures of the second Whole Tone & Kostka-Pane variation are presented in **Figure 10A** next to the harmonization by CHAMELEON from which it originated. The composer informed us that she transposed the harmonic sequence given by CHAMELEON one fifth up (from Am to Em), but apart from adding some extra notes and voice leading, she remained faithful to the backbone harmonic sequence as output by CHAMELEON. Another composer (**Figure 10B**) borrowed an idea from the Jazz CHAMELEON harmonization, that opens the piece with a tonic major (I) chord rather than a tonic minor (i) chord that would be the norm in a minor mode. He also

FIGURE 10 | (A) Left: the beginning of the second variation of the original piece; right: the Whole Tone and Kostka-Pane blend with five semitones tonal difference by CHAMELEON. The harmonic sequence is transposed one perfect fifth up from Am to Em and although there are differences in the spelling of enharmonic notes, in voice leading and some added notes, the harmonic backbone remains the same as the one suggested by CHAMELEON. **(B)** Top left: the beginning of the original piece; top right: measures 23–25; bottom: the Jazz harmonization by CHAMELEON. It can be seen that the tonic major opening chord (I) also appears in the Jazz harmonization as a $I^{7\sharp}$. The 3rd measure of the Jazz harmonization contains a downward chromatic movement in the three top voices that was adopted by the composer in measures 23–25 of his composition.

informed us that he used the tonic major in various instances throughout his piece. One other example of influence in this piece was the adoption of a downward chromatic movement in the three upper voices similar to the 3rd measure of the Jazz harmonization by CHAMELEON.

These examples are only indicative of the many different harmonic possibilities and ideas suggested by CHAMELEON and adopted by the composers in their final works and they demonstrate the potential of human-computer collaborations in music creation. It is important to note that these influences were pointed out by the composers themselves and were not identified through our own analysis. On the contrary, and back to our main experiment, we recently presented a comparative analysis between the computationally supported harmonizations and the favored CHAMELEON examples of each participant that identified a number of different strategies for the creative exploitation of CHAMELEON (Zacharakis et al., 2020) in a melodic harmonization task. Indeed, many participants seemed to have adopted elements as they appeared in their preferred CHAMELEON examples ranging from single chords (most usual) or longer chord sequences to more abstract concepts (less usual).

5. CONCLUSIONS

Through a combination of user experience assessment and computational characterization of the produced harmonizations it has been shown that the use of CHAMELEON resulted in more explorative approaches on a melodic harmonization task, but was appreciated more by novices than experienced composers. At the same time, novel musical compositions inspired by this experiment featured clear influences by CHAMELEON as reported by their own creators. The feedback received from this experiment will be utilized in future versions of the harmonization assistant to improve user experience. Although participants reported that the use of CHAMELEON was easily understandable, they seem to refer primarily to the ability to choose and combine its parameters rather than the understanding of its background processes. The system in its current form is most likely interpreted as a *black box* with unspecified internal processes. It is possible that adding layers of explainability could increase the sense of collaboration between the users and the machine which may in turn increase the sense of overall enjoyment. In addition, transparency regarding how and why the system reaches particular solutions might mitigate beliefs—such as the ones expressed in this study—that consider artificial intelligence as an inappropriate medium for music composition. Future work will investigate the influence of such added features to the experience of using a creative music assistant.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee of the Aristotle University of Thessaloniki. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

AZ, MK-P, SK, and EC participated in the conception and design of the study. AZ and SK conducted the experiments. MK-P created the online version of CHAMELEON and extracted the harmonic features from the obtained melodic harmonizations. AZ performed the statistical analysis. All authors contributed to the writing of the paper, manuscript revision, and approval of the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.603752/full#supplementary-material

Supplementary Figure 1 | The most typical harmonizations of the two melodies used in the experiment as indicated by a professor of music theory.

REFERENCES

Agres, K., Forth, J., and Wiggins, G. A. (2016). Evaluation of musical creativity and musical metacreation systems. *Comput. Entertain.* 14, 1–33. doi: 10.1145/2967506

Albert, R. S., and Runco, M. A. (1999). A history of research on creativity. *Handb. Creat.* 2, 16–31. doi: 10.1017/CBO9780511807916.004

Allan, M., and Williams, C. (2005). "Harmonising chorales by probabilistic inference," in *Advances in Neural Information Processing Systems*, 25–32.

Armstrong, R. A. (2014). When to use the Bonferroni correction. *Ophthal. Physiol. Opt.* 34, 502–508. doi: 10.1111/opo.12131

Boccia, M., Piccardi, L., Palermo, L., Nori, R., and Palmiero, M. (2015). Where do bright ideas occur in our brain? Meta-analytic evidence from neuroimaging studies of domain-specific creativity. *Front. Psychol.* 6:1195. doi: 10.3389/fpsyg.2015.01195

Boden, M. A. (2004). *The Creative Mind: Myths and Mechanisms*. Psychology Press. doi: 10.4324/9780203508527

Bonnardel, N., and Zenasni, F. (2010). The impact of technology on creativity in design: an enhancement? *Creativ. Innov. Manage.* 19, 180–191. doi: 10.1111/j.1467-8691.2010.00560.x

Briot, J.-P., Hadjeres, G., and Pachet, F.-D. (2017). Deep learning techniques for music generation-a survey. *arXiv preprint arXiv:1709.01620*.

Brunner, G., Wang, Y., Wattenhofer, R., and Zhao, S. (2018). "Symbolic music genre transfer with cyclegan," in *2018 IEEE 30th International Conference on Tools With Artificial Intelligence (ICTAI)*, 786–793. doi: 10.1109/ICTAI.2018.00123

Cambouropoulos, E. (2015). "A probabilistic approach to determining bass voice leading in melodic harmonization," in *Mathematics and Computation in Music: 5th International Conference, MCM 2015, Vol. 9110* (London: Springer), 128.

Cambouropoulos, E., Kaliakatsos-Papakostas, M., and Tsougras, C. (2014). "An idiom-independent representation of chords for computational music analysis and generation," in *Proceedings of the Joint 11th Sound and Music Computing Conference (SMC) and 40th International Computer Music Conference (ICMC), ICMC-SMC*, 1002–1010.

Chaudhuri, S., and Koltun, V. (2010). "Data-driven suggestions for creativity support in 3d modeling," in *ACM SIGGRAPH Asia 2010 Papers*, 1–10. doi: 10.1145/1882262.1866205

Cherry, E., and Latulipe, C. (2014). Quantifying the creativity support of digital tools through the creativity support index. *ACM Trans. Comput. Hum. Interact*. 21, 1–25. doi: 10.1145/2617588

Colton, S. (2008). "Creativity versus the perception of creativity in computational systems," in *AAAI Spring Symposium: Creative Intelligent Systems, Vol. 8*.

Colton, S., and Wiggins, G. A. (2012). "Computational creativity: the final frontier?," in *Ecai, Vol. 12* (Montpelier), 21–26.

De Haas, W. B., Robine, M., Hanna, P., Veltkamp, R. C., and Wiering, F. (2010). "Comparing harmonic similarity measures," in *7th International Symposium on Computer Music Modeling and Retrieval*, 299–315.

De Haas, W. B., Rodrigues Magalh aes, J., Veltkamp, R. C., and Wiering, F. (2011). "Harmtrace: Improving harmonic similarity estimation using functional harmony analysis," in *Proceedings of the 12th International Conference on Music Information Retrieval (ISMIR)*.

De Haas, W. B., Veltkamp, R. C., and Wiering, F. (2008). "Tonal pitch step distance: a similarity measure for chord progressions," in *ISMIR*, 51–56.

Ebcioğlu, K. (1988). An expert system for harmonizing four-part chorales. *Comput. Music J*. 12, 43–51. doi: 10.2307/3680335

Eppe, M., Confalonieri, R., Maclean, E., Kaliakatsos, M., Cambouropoulos, E., Schorlemmer, M., et al. (2015). "Computational invention of cadences and chord progressions by conceptual chord-blending," in *Twenty-Fourth International Joint Conference on Artificial Intelligence*.

Fauconnier, G., and Turner, M. (2003). *The Way We Think: Conceptual Blending and the Mind's Hidden Complexities*. Basic Books.

Goguen, J. (2006). "Mathematical models of cognitive space and time," in *Reasoning and Cognition: Proc. of the Interdisciplinary Conference on Reasoning and Cognition*, 125–128.

Hadjeres, G., Pachet, F., and Nielsen, F. (2017). "Deepbach: a steerable model for bach chorales generation," in *Proceedings of the 34th International Conference on Machine Learning-Vol. 70*, 1362–1371.

Heyduk, R. G. (1975). Rated preference for musical compositions as it relates to complexity and exposure frequency. *Percept. Psychophys*. 17, 84–90. doi: 10.3758/BF03204003

Johnson-Laird, P. N. (1988). Freedom and constraint in creativity. The nature of creativity: Contemporary psychological perspectives, 202.

Jordanous, A. (2012). A standardised procedure for evaluating creative systems: computational creativity evaluation based on what it is to be creative. *Cogn. Comput*. 4, 246–279. doi: 10.1007/s12559-012-9156-1

Jordanous, A. (2016). Four PPPPerspectives on computational creativity in theory and in practice. *Connect. Sci*. 28, 194–216. doi: 10.1080/09540091.2016.1151860

Jordanous, A., and Keller, B. (2016). Modelling creativity: Identifying key components through a corpus-based approach. *PLoS ONE* 11:e162959. doi: 10.1371/journal.pone.0162959

Kaliakatsos-Papakostas, M., Floros, A., and Vrahatis, M. N. (2020). "Artificial intelligence methods for music generation: a review and future perspectives," in *Nature-Inspired Computation and Swarm Intelligence* (Elsevier), 217–245. doi: 10.1016/B978-0-12-819714-1.00024-5

Kaliakatsos-Papakostas, M., Queiroz, M., Tsougras, C., and Cambouropoulos, E. (2017). Conceptual blending of harmonic spaces for creative melodic harmonisation. *J. New Music Res*. 46, 305–328. doi: 10.1080/09298215.2017.1355393

Kaliakatsos-Papakostas, M. A., Epitropakis, M. G., and Vrahatis, M. N. (2010). "Musical composer identification through probabilistic and feedforward neural networks," in *European Conference on the Applications of Evolutionary Computation* (Springer), 411–420. doi: 10.1007/978-3-642-12242-2_42

Kantosalo, A., and Riihiaho, S. (2019). Experience evaluations for human-computer co-creative processes-planning and conducting an evaluation in practice. *Connect. Sci*. 31, 60–81. doi: 10.1080/09540091.2018.1432566

Kostka, S., and Payne, D. (2013). *Tonal Harmony*. McGraw-Hill Higher Education.

Lerdahl, F. (2004). *Tonal Pitch Space*. Oxford University Press. doi: 10.1093/acprof:oso/9780195178296.001.0001

Lubart, T. (2005). How can computers be partners in the creative process: classification and commentary on the special issue. *Int. J. Hum. Comput. Stud*. 63, 365–369. doi: 10.1016/j.ijhcs.2005.04.002

Luft, C. D. B., Zioga, I., Thompson, N. M., Banissy, M. J., and Bhattacharya, J. (2018). Right temporal alpha oscillations as a neural mechanism for inhibiting obvious associations. *Proc. Natl. Acad. Sci. U.S.A*. 115, E12144–E12152. doi: 10.1073/pnas.1811465115

Massetti, B. (1996). An empirical examination of the value of creativity support systems on idea generation. *MIS Quart*. 83–97. doi: 10.2307/249543

McCrae, R. R. (1987). Creativity, divergent thinking, and openness to experience. *J. Pers. Soc. Psychol*. 52:1258. doi: 10.1037/0022-3514.52.6.1258

Mooney, R. L. (1963). "A conceptual model for integrating four approaches to the identification of creative talent," in *Scientific Creativity: Its Recognition and Development*, eds C. W. Taylor and F. Barron (New York, NY: John Wiley & Sons), 331–340.

Odena, O., and Welch, G. (2009). A generative model of teachers' thinking on musical creativity. *Psychol. Mus*. 37, 416–442. doi: 10.1177/0305735608100374

Raczyński, S. A., Fukayama, S., and Vincent, E. (2013). Melody harmonization with interpolated probabilistic models. *J. New Mus. Res*. 42, 223–235. doi: 10.1080/09298215.2013.822000

Rhodes, M. (1961). An analysis of creativity. *Phi Delta Kappan* 42, 305–310.

Ritchie, G. (2007). Some empirical criteria for attributing creativity to a computer program. *Minds Mach*. 17, 67–99. doi: 10.1007/s11023-007-9066-2

Roberts, A., Engel, J., and Eck, D. (2017). "Hierarchical variational autoencoders for music," in *NIPS Workshop on Machine Learning for Creativity and Design*.

Rosen, D., Oh, Y., Erickson, B., Zhang, F. Z., Kim, Y. E., and Kounios, J. (2020). Dual-process contributions to creativity in jazz improvisations: an SPM-EEG study. *NeuroImage* 2020:116632. doi: 10.1016/j.neuroimage.2020.116632

Runco, M. A., and Acar, S. (2012). Divergent thinking as an indicator of creative potential. *Creat. Res. J*. 24, 66–75. doi: 10.1080/10400419.2012.652929

Shneiderman, B. (2007). Creativity support tools: accelerating discovery and innovation. *Commun. ACM* 50, 20–32. doi: 10.1145/1323688.1323689

Shneiderman, B., Fischer, G., Czerwinski, M., Resnick, M., Myers, B., Candy, L., et al. (2006). Creativity support tools: report from an us national science foundation sponsored workshop. *Int. J. Hum. Comput. Interact*. 20, 61–77. doi: 10.1207/s15327590ijhc2002_1

Stein, M. I. (1953). Creativity and culture. *J. Psychol*. 36, 311–322. doi: 10.1080/00223980.1953.9712897

Wiggins, G. A. (2006). A preliminary framework for description, analysis and comparison of creative systems. *Knowl. Based Syst*. 19, 449–458. doi: 10.1016/j.knosys.2006.04.009

Wiggins, G. A. (2008). Computer models of musical creativity: a review of computer models of musical creativity by david cope. *Liter. Linguist. Comput*. 23, 109–116. doi: 10.1093/llc/fqm025

Wiggins, G. A., Tyack, P., Scharff, C., and Rohrmeier, M. (2015). The evolutionary roots of creativity: mechanisms and motivations. *Philos. Trans. R. Soc. B Biol. Sci*. 370:20140099. doi: 10.1098/rstb.2014.0099

Zacharakis, A., Kalaitzidou, S., Kaliakatsos-Papakostas, M., and Cambouropoulos, E. (2020). "Good artists copy, great artists steal: strategies for creative exploitation of the chameleon harmonisation assistant," in *Proceedings of the 17th Sound and Music Computing Conference*, 228–233.

Zacharakis, A., Kaliakatsos-Papakostas, M., Tsougras, C., and Cambouropoulos, E. (2018). Musical blending and creativity: an empirical evaluation of the chameleon melodic harmonisation assistant. *Mus. Sci*. 22, 119–144. doi: 10.1177/1029864917712580

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The Role of Canalization and Plasticity in the Evolution of Musical Creativity

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Creativity is defined as the ability to generate something new and valuable. From a biological point of view this can be seen as an adaptation in response to environmental challenges. Although music is such a diverse phenomenon, all people possess a set of abilities that are claimed to be the products of biological evolution, which allow us to produce and listen to music according to both universal and culture-specific rules. On the one hand, musical creativity is restricted by the tacit rules that reflect the developmental interplay between genetic, epigenetic and cultural information. On the other hand, musical innovations seem to be desirable elements present in every musical culture which suggests some biological importance. If our musical activity is driven by biological needs, then it is important for us to understand the function of musical creativity in satisfying those needs, and also how human beings have become so creative in the domain of music. The aim of this paper is to propose that musical creativity has become an indispensable part of the gene-culture coevolution of our musicality. It is suggested that the two main forces of canalization and plasticity have been crucial in this process. Canalization is an evolutionary process in which phenotypes take relatively constant forms regardless of environmental and genetic perturbations. Plasticity is defined as the ability of a phenotype to generate an adaptive response to environmental challenges. It is proposed that human musicality is composed of evolutionary innovations generated by the gradual canalization of developmental pathways leading to musical behavior. Within this process, the unstable cultural environment serves as the selective pressure for musical creativity. It is hypothesized that the connections between cortical and subcortical areas, which constitute cortico-subcortical circuits involved in music processing, are the products of canalization, whereas plasticity is achieved by the means of neurological variability. This variability is present both at the level of an individual structure's enlargement in response to practicing (e.g., the planum temporale) and within the involvement of neurological structures that are not music-specific (e.g., the default mode network) in music processing.

Keywords: canalization, plasticity, gene-culture coevolution, musical creativity, musical syntax, cortico-subcortical loops, premotor cortex

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INTRODUCTION

Music has been observed in all human cultures and has accompanied our ancestors since the dawn of our species (Morley, 2013), or perhaps even earlier as part of ancient hominin behavior (Mithen, 2006). Therefore, musicality as a set of abilities that enable music production and recognition (Fitch, 2015), is often claimed to be a product of biological evolution (Roederer, 1984; Hagen and Bryant, 2003; Peretz, 2006; Hagen and Hammerstein, 2009; Mithen, 2009). As music has its roots in the vocal behavior of our ancestors (Bannan, 2012; Morley, 2013), the evolution of musical creativity cannot be explained without tracing the beginnings of hominin vocal communication. Singing, the vocal form of musical activity, belongs together with crying, laughter and speech, as a group of characteristic vocalizations of *Homo sapiens*, and is often compared with songbirds' songs (Merker, 2005; Fitch and Jarvis, 2013; Rothenberg et al., 2014) or the songs of other species (Geissmann, 2000; Payne, 2000). Human and songbird songs are good examples of ritual culture because the structures of their songs are the objects of imitation by conspecifics (Merker, 2009). In order to achieve this trait, the evolution of vocal learning among songbirds and hominins was necessary. Another important similarity between human and songbird songs is that both humans and songbirds modify their songs so that new versions become an object of cultural transmission. This means that apart from an urge to imitate a song, individuals are also prone to invent at least some new structural elements. This task necessitates both the knowledge of rules that govern a particular song style and creativity, as not all possible sound variants can be recognized as a song and therefore appreciated by conspecifics. From this point of view, musical creativity, similar to songbird vocal creativity, should not only have the ability to generate something novel and original in the domain of music, but also have something valuable (Merker, 2006). The invention of any new musical piece must be a result of the "creative thinking process" which in music can be viewed as consisting of three stages: (i) product intentions, (ii) the thinking process, and (iii) the creative product (Webster, 1990, 2002). While the product intentions phase is strictly related to the kind of urge that drives a creator to musical activity (e.g., composition, performance, improvisation) the thinking process is based on divergent and convergent thoughts (Webster, 2002). Divergent thoughts involve the imagination of musical elements such as melodic or rhythmic motives (Webster, 2002) which can occur involuntarily (Copeland, 2019). In contrast, convergent thoughts seem to be analytical and lead to aesthetic decisions (Webster, 2002). Only after this is the final creative product achievable. Since the result of an effective creative process in music is usually positively assessed by a social environment, being creative gives an advantage to creative individuals. Therefore, musical creativity can be viewed as a biological adaptation. As every creative act operates on the existing cultural information, musical creativity can also be understood as "an adaptive process of knowledge acquisition" (Reybrouck, 2006). However, while creativity in general refers to the ability that allows us to use all possible cognitive resources, the creative process in the domain of song is restricted by the scope of sound features which characterize conspecific songs. Therefore, in contrast to general creativity that is often understood as being free from any limitations, the evolutionary beginnings of creative abilities in the domain of song seem to be tightly connected to a domain-specific form of communication.

The fact that humans are so constrained by music-specific features (Harwood, 1976; Nettl, 2000; Brown and Jordania, 2011; Savage et al., 2015; Mehr et al., 2019) and at the same time so creative while inventing the variations of a sound sequence, suggests that human musicality must be based on at least two antithetical predispositions. One impels humans to be as precise as possible in copying musical distinctive sound features. This copying capacity is possible thanks to a human ability unique among primates to vocally learn (Janik and Slater, 1997; Merker, 2005, 2012), especially the sounds of speech and singing (Bannan, 2008). The other predisposition allows us to be inventive enough to create sound sequences that are ear-catching for the other members of a social group. Without this ability, no variations of music, and thus any cultural evolution of music, would be possible (Savage, 2019). By taking into account the contrastive character of the aforementioned abilities, a multistage evolutionary scenario must be considered to explain the origin of musical creativity. After all, it is hard to imagine how such a complex variability of human songs could have evolved as a result of one accidental event. Instead, the appearance of musical creativity as we know it today must have been evolving gradually in response to many evolutionary pressures. On the one hand, these pressures must have led to the appearance of music-specific perceptive, functional and behavioral biases (Mehr et al., 2019). On the other hand, these biases must not have been strong enough to restrict the scope of hominins' vocal repertoire to a closed set of calls. The result is *Homo sapien* musical culture which can be characterized by the influence of at least four levels of constrains: (1) inherited perceptive and behavioral biases which influence the existence of musical universals; (2) enculturated (culturally inherited) biases which consists of implicitly learned elements of a musical system such as culture-specific pitch intervals and rhythm ratios; (3) limitations of creativity which are related to the efficiency of the brain, restricted for instance, by the capacity of working memory; (4) social selective pressures which act as feedback able to modify former constraints in the long run. The existence of all these constraints indicates that gene-culture coevolution (Lumsden and Wilson, 1980) could have been an evolutionary mechanism leading to the origins of human musicality (Podlipniak, 2015, 2017; Killin, 2016, 2017; Patel, 2018; Savage et al., 2020). It is worth mentioning, that all these aforesaid constraints act simultaneously and must have been present at all stages of our gene-culture coevolution, which has led to the emergence of human musical culture. Therefore, the evolution of musical creativity, being an inseparable part of this process, must have been influenced, at least, by some of the same evolutionary forces that have shaped the evolution of human musicality.

This paper takes a theoretical and naturalistic approach in order to explain the evolutionary roots of musical creativity. Since musical creativity is based on innovative thinking in the domain of sound communication, the presented framework is focused only on the relatively recent evolutionary history of the *Homo* lineage in which vocal learning started to play an important role, rather than depicting the whole evolutionary origin of human musicality. We begin with the idea of gene-culture coevolution and its aforementioned two main evolutionary mechanisms—plasticity and canalization. The next section is devoted to the conditions that influenced the evolution of musical creativity, in which the point of departure for the coevolutionary pathways leading to emergence of human musicality is demonstrated, including details concerning the possible interplay between canalized and innovative factors in the domain of pitch and rhythm. In the following section, the view of musical syntax as a canalized framework for musical creativity is discussed. In the conclusion the importance of musical creativity for the evolution of human musicality is emphasized, and possible future research that can contribute to the evolutionary explanation of the origin of musical creativity is suggested.

PLASTICITY AND CANALIZATION AS THE MAIN MECHANISMS OF GENE-CULTURE COEVOLUTION

In general, gene-culture coevolution is a circular process in which genetic information influences culture whilst also simultaneously changing in response to culture that acts as a selective environment (Lumsden and Wilson, 1982). The influence of genetic information on culture can be achieved by different mechanisms related to either somatic characteristics or behavioral proclivities. Wilson (Wilson, 1978) described this influence metaphorically by saying that "the genes hold culture on a leash" (p. 167). These mechanisms restrict the type of cultural information to be exchanged (e.g., the dominance of visual and acoustic cues as the means of communication in primates) but they also allow a species to create a species-specific cultural niche (e.g., agriculture). However, apart from being under such constraints many animals are able to socially learn (Laland, 2017) which makes them flexible at overcoming new challenges that can appear in a fast-changing environment. Such flexibility is especially useful in a complex and often fast changing cultural environment that characterizes human culture. Nonetheless, not all cultural traits change equally fast. When a particular cultural environment is stable enough, i.e., it lasts throughout many generations; it can become a source of selection. As a consequence, such a stable cultural environment can lead to the appearance of traits that are under genetic control. The clearest example of gene-culture coevolution is the evolution of lactase persistence (Gerbault et al., 2011). It is assumed that the domestication of animals by humans created a pastoral cultural niche which became a selective environment for the appearance of lactose tolerance among adults about 8,000 years ago (Leonardi et al., 2012). As a result, a population dominated by individuals characterized by lactose tolerance has been prone to sustain and elaborate the practice of dairying. In this example, a cultural invention—farming—became a starting point for a chain of interdependent coevolutionary events. Similar coevolutionary mechanisms have been proposed for the evolution of many human traits such as handedness, mating preference (Laland, 2008), language (Dor and Jablonka, 2000, 2001; Bickerton, 2010; Deacon, 2010) and music (Podlipniak, 2017; Patel, 2018; Savage et al., 2020). Music in gene-culture coevolution was initially invented by hominins and by having an adaptive function, music abilities have been preferred by natural selection which has strengthened and accelerated the evolution of human musicality. According to Patel for example, the invention of music had unexpected adaptive effect—social bonding, which was the cause of the coevolutionary chain of circumstances (Patel, 2018). In another coevolutionary scenario of music evolution (Podlipniak, 2017), the social bonding function was an attribute of music right from the beginning. In all these scenarios, however, genes and culture has been permanently interacting.

Plasticity

The necessary condition for gene-culture coevolution is the ability of phenotypes to modify behavior in response to the environment. This kind of response is often called behavioral plasticity (Dor and Jablonka, 2010; Mery and Burns, 2010), a form of developmental (or phenotypic) plasticity (Pigliucci, 2001; Fusco and Minelli, 2010) which, along with genetic variation, is the property of all living organisms (West-Eberhard, 2005). Thanks to plasticity every phenotype can be flexible to some extent, which allows it to adapt in response to environmental changes during its lifetime. For behavioral plasticity to occur a phenotype has to learn. Although behavioral plasticity and learning are often associated with neuronal plasticity, both can be achieved by other mechanisms too (Jablonka and Lamb, 2005; Mery and Burns, 2010). It must be emphasized, however, that developmental, including behavioral, plasticity being the terms that refer to the functional explanation of the adaptation to the environment (the survival value of a trait), belongs to Tinbergen's ultimate level of explanation (Tinbergen, 1963) which focuses on the phylogeny and function of a phenotypic trait (Fitch, 2015). In contrast, neuronal plasticity as a physiological mechanism that allows the brain to modify the preexisting neuronal connections in response to changes in afferent inputs or efferent requirements (Pascual-Leone et al., 2005) represents Tinbergen's proximal level of explanation (Tinbergen, 1963), which concerns the mechanistic and developmental elucidations of how a phenotypic trait works and develops in ontogeny (Fitch, 2015). Therefore, although behavioral plasticity can be achieved by the means of neuronal plasticity, only the former refers to the gene-culture coevolutionary explanations of the appearance of musical creativity.

From this perspective plasticity is a crucial process that enables cultural change. It seems that plasticity has played a crucial role in the evolution of humans, since our culture is cumulative (Tomasello, 1999), which means that cultural traits such as behaviors, technologies and ideas are not only learned and transmitted from generation to generation but also modified and improved so that new elements are often added to the existing ones. An increasing number of innovations and modifications lead to the appearance of a rich cultural environment which undergoes its own evolution. The process of cultural evolution resembles to some extent genetic evolution (Creanza et al., 2017), since in both cases the gradual process of transmission and modification of traits by means of natural selection is observed. This means that all cultural traits have to compete to reproduce (cultural transmission). However, in contrast to genetic evolution in which variations of traits are achieved by means of mutations and recombination, at the level of cultural evolution plasticity is a source of diversity. Moreover, without plasticity the interaction between cultural and genetic evolution would be impossible. After all, thanks to plasticity the first Anatolian farmers were able to invent a dairy based diet which started the gene-culture coevolution of the aforementioned lactase persistence.

Canalization

The concept of "canalization" was originally proposed by Waddington (1942) and refers to "the ability of a genotype to produce relatively constant phenotypes regardless of environmental and genetic variabilities" (Takahashi, 2019, p. 14; cf. also Dor and Jablonka, 2010, p. 138; Loison, 2019, p. 6). Importantly, such constancy concerns not only somatic but also behavioral traits. Canalization can be achieved by different means including cultural and genetic control over a given trait. A good example of an evolutionary mechanism related to gene-culture coevolution in which canalization plays a crucial role is the Baldwin effect (Baldwin, 1896a,b; Sznajder et al., 2012). In the first step of the Baldwinian mode of evolution, organisms adapt to the environmental challenges by means of phenotypic adaptation. In the case of culturally achieved phenotypic adaptation, adaptive learning plays a crucial role. Thanks to genetic variability of a population, sooner or later a new genotype appears and endues an individual with an instinct allowing the replacement of phenotypic adaptation with genetic adaptation (Dor and Jablonka, 2000). If this learning is costly, i.e., it needs a lot of energy and/or is time-consuming, such an individual is favored by natural selection and in the long run the whole population becomes dominated by individuals endowed with this instinct. In other words, in these circumstances a trait that is initially achieved by plastic response to environmental pressure is followed by a genetic change which takes control over the previously culturally achieved trait. The ability to develop this trait, independent of whether it is achieved by learning or genetic control, represents an example of canalization. Different circumstances can promote either plasticity or canalization. While plasticity is an effective mechanism for adaptation to a fast-changing environment, canalization can be viewed as a safety-valve based on evolutionary "memory." As such, canalization can be understood as "the buffering of environmental and genetic <<noise>>" (Dor and Jablonka, 2010, p. 135).

THE EVOLUTION OF THE MUSICAL MIND AND MUSICAL CREATIVITY

The processing of music is a complex task which consists of many sequential and simultaneous computations that reflects different adaptive mechanisms of a different evolutionary age. Only a small part of these processes can be viewed as music-specific. The vast majority of these mechanisms fulfill more general functions related to audition, including auditory scene analysis such as the detection and recognition of sound sources (Bregman, 1990), and various forms of acoustic communication (Zimmermann et al., 2013; Ackermann et al., 2014; Scheumann et al., 2014), a lot of which humans share with other animal species. Although many of these non-music-specific abilities are necessary for music perception, they are not sufficient to experience music in its whole structural and meaningful form. After all, only *Homo sapiens* among all living primates is able to vocalize syntactically organized and culturally transmitted sound patterns based on rhythm and pitches. Of course, this does not mean that human musicality evolved from scratch. On the contrary, many preadaptations among our ancestral primates must have existed to allow natural selection to design music-like behavioral traits in some evolutionary lineages of primates. A good example of such a behavioral trait can be found in gibbon songs (Geissmann, 2000; Merker, 2000). This opens the possibility that even the common ancestor of great and lesser apes was endowed with the abilities to allow some form of singing (Jordania, 2014). However, taking into account that gibbon songs are under strong genetic control rather than being vocally learned calls (Brockelman and Schilling, 1984), it is reasonable to assume that the evolution of culturally flexible musical behavior among hominins was influenced by additional factors. This means that human-specific musical brain equipment had to have evolved relatively recently after the split between the common ancestor of chimpanzees and hominins. This equipment must have allowed our ancestors to use sounds as culturally heritable units. This ability let our ancestral hominins to partially free their vocalizations from affective calls (Ackermann et al., 2014). The unchained vocal calls became based on discrete units which became the units of cultural inheritance (Savage, 2019). Moreover, the sequences of these units, being culturally transmitted information, started to be the objects of modification. This is the evolutionary stage where plasticity and creativity started to act in the domain of vocal communication.

Environmental Sounds, Speech, and Music

Although vision is the dominant sense among primates (in humans for instance the processing of visual signal involves a remarkably bigger amount of neural tissue than the processing of auditory stimuli; Deutsch, 2019), hearing is still an important source of information about the environment for humans and the same must have been true for hominins. Therefore, it is not surprising that auditory information serves as an additional clue to navigate in the world (Horowitz, 2012). However, apart from inferring information about the environment, primates also use sound to transmit signals concerning their intentions (Hauser and Konishi, 1999; Hauser, 2000). Since primates are able to auditory learn, i.e., to associate sounds with referential meaning (Wright et al., 1990) and chimpanzees even modify and use sounds as sound symbols (Watson et al., 2015), it is reasonable to assume that hominins were able to use sounds intentionally as a medium of communication. It has been proposed that the increasing role of sociality among hominins that belong to the lineage leading to *Homo sapiens*, created an evolutionary pressure for the development of intentional vocalizations, i.e., speech and singing (Dunbar, 1996). The conscious intentionality of vocal expressions imposes a set of new properties on the production and processing of sound. First of all, the coding of meaning in vocally produced sounds necessitates the vocal control over the acoustic features of vocalized sounds. Secondly, the acoustic features of sound must be linked together with meaningful mental categories. Thirdly, these mental categories must be processed separately in order to avoid confusion in the process of decoding information. Fourthly, auditory perception should be biased in favor of acoustic features that are crucial for the conspecific intentional vocalizations. Fifthly, the intentional vocalizations should be ductile enough to code new meaningful elements. Finally, these elements should be prone to be learnable, i.e., to be culturally inherited. All these properties characterize the production and processing of both speech and singing.

Human vocal learning is especially efficient as far as the speech and singing features are concerned (Jackendoff and Lerdahl, 2006). The mental categories of words in speech and musical pitches and rhythms in music are mapped into conceptual meaning (Bickerton, 2009) and preconceptual emotional (Podlipniak, 2020) and kinetic impressions (Grahn and Rowe, 2009, 2013; Levitin et al., 2018), respectively. Although neuroimaging studies show that certain brain areas are involved in the processing of both language and music (Fedorenko et al., 2009; Kunert et al., 2015) there are also neural structures that are activated when only one of these two phenomena is processed (Rogalsky et al., 2011; Perruchet and Poulin-Charronnat, 2013; Norman-Haignere et al., 2015). This dissociation indicates the existence of language and music specific networks. The perceptive preference for the specific features of speech and music is observed in children right after birth (Fassbender, 1996; McMullen and Saffran, 2004; Perani et al., 2010; Brandt et al., 2012). Finally, both language and music represent a recursive open system (Merker, 2002; Pinker and Jackendoff, 2005), which means that humans are able to produce an enormous number of new and original musical and speech phrases. Importantly, in contrast to many songbird species, humans are prone to learn and modify these phrases during their whole life. However, some elements of speech and music such as phonemes and pitch intervals seem to be easier to learn in childhood whereas some, such as new words or new musical phrases, are equally easy to learn during adulthood (Trainor, 2005; White et al., 2013; Li et al., 2014; Friedmann and Rusou, 2015; Birdsong, 2018). This suggests that learning plasticity is a complex ability that consists of selective constraints which act differently at different stages of development.

Rhythm, Movement, Pitch, and Vocal Learning

The music specific elements of musical code are discrete rhythm measures and pitch intervals. Since both these musical features have been recognized as musical universals (Brown and Jordania, 2011; Savage et al., 2015; Trehub, 2015; Mehr et al., 2019) it is reasonable to assume that music communication is based on sounds interpreted by human minds in term of discrete pitches and rhythms. Moreover, rhythm measures and pitch intervals are crucial for musical syntax. However, discrete pitches and rhythms can exist independently as in music based solely on rhythm, as well as in non-metrical music, e.g., in some oral traditions of Gregorian chanting, respectively. This indicates that the processing of musical pitch and the processing of musical rhythm are in fact separate abilities. Therefore, human musicality cannot be treated as a monolithic entity or as a product of one evolutionary episode. Indeed, many scholars have proposed the multistage scenarios of music's origins (Mithen, 2006). In the majority of these scenarios, musical rhythm is usually indicated as evolutionarily more ancient than musical pitch.

Musical rhythm is organized in a framework based on the sensation of periodicity known as musical pulse. Additionally, this framework is usually organized into hierarchical beat patterns called meters (London, 2012). This means that our perception of musical rhythm is based on precise mental expectations concerned with when sounds may occur (Huron, 2006). The evolutionary roots of musical rhythm have often been searched for in the coupling between auditory signals and movement. The main hint for such a claim is that humans spontaneously synchronize their movements with musical beat, the perception of which is based on the sensation of musical pulse. It is also known that the processing of isochronous musical stimuli involves the activity of motor brain areas including cortico-striatal loops (Geiser et al., 2012). This can additionally suggest that our perception of musical meter is at least partly based on motor experience (Repp, 2007). Therefore, rather than auditory, music is an auditory-motor phenomenon which along with its time dependence, makes music experience and creativity unique (Bashwiner, 2018) among other human sound expressions. The ability of auditory-motor synchronization affects not only one individual, but also the social level of behavior by allowing people to move together in synchrony in response to music. It has been also proposed that apart from movement synchronization, collective listening to music leads to the alignment of brain states (Bharucha et al., 2011).

Although the human ability to synchronize movements with beat seems to be exceptional among primates, there are studies which indicate that motor-beat synchronization restricted to 600ms periodicity can be achieved by chimpanzees (Hattori et al., 2013, 2015). Chimpanzees are also prone to rhythmic swaying in response to auditory stimuli and the beat rate of these stimuli influences the periodicity of chimps swaying in a bipedal position (Hattori and Tomonaga, 2020). These observations suggest that primitive auditory-motor coupling was present in the last common ancestor of *Homo sapiens* and chimpanzees. This coupling could have probably been one of the ancient preadapations for human musicality. However, while auditory-motor synchronization among chimpanzees is restricted to a narrow scope of tempi (Hattori et al., 2013), humans are able to spontaneously synchronize with isochronous auditory stimuli in a multi-timescale (Parncutt, 1994; Toiviainen et al., 2010; Patel and Iversen, 2014). The widening of a beat extraction timescale is a good example of a change that enables plasticity in the domain of beat perception and production. Therefore, while the first hominins were most probably unable to use sounds in different timescales, the broadening of beat sensitivity among the next generations of hominins opened the window of creativity in the domain of rhythm. Although the change of tempo does not seem to be a very creative task for humans today, it must have been a great achievement for hominins. The extension of a beat extraction timescale was also a necessary condition for the development of rhythm measures quantification. As a result of this, the perception of rhythm measures in terms of simple integer ratios is nowadays a cross-cultural universal feature of human music perception (Jacoby and McDermott, 2017). However, having many rhythm measures available, hominins developed a medium of communication susceptible to cultural change and inventions. Therefore, on the one hand the abilities to align movements with beat and to quantify rhythm measures in terms of simple integer ratios are the examples of canalized skills. At the neuronal level the ability of beat extraction is based on cortico-striatal loops, especially on connections between the supplementary motor area, the premotor cortex, auditory cortex and the putamen (Grahn and Rowe, 2009). This suggests that the evolution of hominins' auditory-motor synchronization has been achieved by the development of these cortico-subcortical connections. On the other hand, the possibility of sensing different periodicities as musical pulse along with flexibility in the use of rhythm measures became an area of behavioral plasticity, due to the fact that both the striatum and the neocortex belong to the major sites of synaptic plasticity in the brain enabling learning (Pascual-Leone et al., 2005; Surmeier et al., 2009; Perrin and Venance, 2019). Both the ability of beat extraction and the sense of different periodicities most probably became the first capacities which enabled divergent musical thought composed of rhythmic kernels of musical thinking (Webster, 2002). Note however, that neither all canalized rhythmical skills, nor the whole scope of plasticity in the domain of musical rhythm appeared at the same time in the evolution. In order to allow hominins to evolve into a rhythmically creative species like *Homo sapiens,* a chain of successive behavioral changes had to take place. The first step in this process had to be a gradual extension of beat extraction timescale. It is possible that this step could have been achieved previously by means of behavioral plasticity. However, the scope of creativity in the domain of beat extraction must have been constrained by the restricted range of possible periodicities. This range must have gradually broadened until the appearance of anatomically modern humans in whom it reaches the span of 300–900 ms (Toiviainen et al., 2010). Importantly, beat extraction is prone to enculturation which additionally restricts creativity (London, 2012). Even today people from different cultures are biased to sense different pulse of the same music sequence depending on their cultural background (Agawu, 1987). Nonetheless, this kind of culturally induced constraint can be overcome by a creative individual thanks to often conscious convergent thinking that interplays with divergent thinking (Webster, 2002).

Another supposed area of the interplay between plasticity and canalization in the evolution of music creativity is the domain of musical pitch. Pitch in music is usually perceived as a sequence of discrete sensations representing pitch intervals (Krumhansl, 1990; Rakowski, 1999, 2009); thus, creativity in this domain may consist of composing subsequent pitches in a melody and sometimes in changing the size of pitch intervals. In contrast to the experience of musical rhythm which is based on the predictions about sound timing that are independent of the spectral characteristic of the sounds, musical pitch is sensed only if the perceived sound contains harmonics. The crucial acoustic parameter that influences the sensation of pitch is fundamental frequency (F_0). Simply speaking, while musical rhythm tells us "when" sounds occur, musical pitch answers the question about the content of musical sequence. Not only humans use harmonic sounds as a medium of coding their intentions. Many other species, including primates, communicate using sound frequency modulation (Hauser and Konishi, 1999; Hauser, 2000; Horowitz, 2012). Continuous changes of sound frequency are parts of the affective calls of nonhuman primates (Zimmermann et al., 2013; Scheumann et al., 2014). This indicates that hominins also had to use pitch in their calls. However, a leap forward in the evolution of musical creativity was the appearance of digital (discrete) elements of vocalizations. In contrast to affective calls, the features of which are present also in human affective prosody in speech, the digital forms of human vocalizations (articulate speech and singing) are subjects to greater volitional control which gives more space for creativity.

Although not only pitch is used in a discrete form in human vocal expressions, as in the case of vowels and consonants in speech (Jackendoff, 2009), harmonic sounds must have been pivotal in the evolution of both music and speech. The appearance of digital vocal communication was possible thanks to vocal learning—the ability that allows us to vocally reproduce the acoustic parameters of the sounds that we hear (Janik and Slater, 1997; Merker, 2012). The evolution of vocal learning is also related to increased cortico-striatal connectivity (Jarvis, 2007; Fitch and Jarvis, 2013). Although humans are not equally good at vocal learning of all sounds, we are especially predisposed to imitate the distinctive elements of speech and singing. In other words, our cognitive system is biased in favor of speech formats and F_0 of sounds in terms of their perception as well as production. Yet the volitional vocal control of F_0 was the most important evolutionary change (Bannan, 2012) that initiated the creative use of discrete pitch. Only having the ability to sustain F_0 of sung sounds and to master the size of vocalized pitch intervals allowed hominins to be inventive in producing original sequences of discrete pitches. Therefore, while the vocal learning biases became the canalized roots of music and speech development, the establishment of the basic discrete units of speech and music—e.g., phonemes of a particular language and discrete pitches of culture-specific musical system—represents the scope of plasticity. However, it is possible that at the ancient stages of hominins' vocalizations, the choice of spectral cues (F_0 or speech formants) as the distinctive features of discrete vocalization units was also established by means of behavioral plasticity. It is well known that practicing music can lead to the enlargement of and the induction of neuroplasticity in cortical areas involved in the processing of pitch information such as the planum temporale (Meyer et al., 2012; Bashwiner et al., 2016) as well as to the increased connectivity between areas involved in music processing such as the auditory, the sensorimotor, and the prefrontal cortices (Klein et al., 2016). Such neuronal mechanisms enable behavioral plasticity and could have been present to some extent in early musical hominins allowing them to create discrete vocalizations. The fact that there is a correspondence between the number of vowels in language and the number of pitches in musical scales, as well as a relationship between vowel formants and F_0 in song based on meaningless syllables (Fenk-Oczlon, 2017) can support such a scenario. Only after a persistent use of F_0 as a culturally learned distinctive clue for the recognition of song units did the perceptive bias in favor of musical pitch appear. From a cognitive point of view, the perceptive biases in favor of musical pitch and regularity in musical rhythm consist of an active search for relevant information ignoring irrelevant acoustic features. These biases restrict musical creativity in a similar way to phonemic constraints in language (Merker, 2006). The appearance of musical pitch extended the scope of mental categories that constitute the units of musical thoughts present in Webster's divergent thinking phase (Webster, 2002).

MUSICAL SYNTAX AS A CANALIZED FRAMEWORK FOR MUSICAL CREATIVITY

The perceptive biases that constrained musical creativity in the domain of rhythm and pitch structure are not restricted solely to the active search for the distinctive features of musical discrete units. Music similar to language is a complex communicative tool, the structure of which is governed by syntactic rules (Lerdahl and Jackendoff, 1983). These rules mean that musical structure is perceived in terms of two types of hierarchy—rhythm hierarchy based on meter (London, 2012) and pitch hierarchy based on pitch centricity (Krumhansl and Cuddy, 2010). From this point of view music represents a generative and recursive system known as the Humboldt system (Merker, 2002), which allows people to create an enormous number of socially appreciated music sequences. This enormity of such sequences does not mean, however, that every sequence of sound can be recognized as correct. Quite the opposite, there is at least an equally big set of sound sequences that are unacceptable by a social group as faultless musical pieces. This means that even a musically untrained listener is able to recognize syntactical faults in musical sequences such as an out-of-key note in a tonal sequence (Tillmann et al., 2000; Gorzelańczyk et al., 2017). Such a tacit recognition of faults resembles the feelings that accompany native speakers when they listen to grammatical errors in their mother tongues. The main difference between music and language in this respect is that word hierarchies (grammatical relations) are conceptual. Although musical syntax, in contrast to language, is not related to propositional semantics (Lerdahl, 2013) the structural hierarchies in music are easily recognizable by means of emotional clues. It is assumed that the emotional response to sound sequences occurs as a result of fulfilling or not the predictions based on the implicit statistical learning of sound distribution in the musical environment.

The fact that musical syntax is learned implicitly and spontaneously in childhood suggests the existence of developmental predispositions related to this task. It has been hypothesized that the ability to recognize pitch center (Podlipniak, 2016), as well as to organize musical pitch in a syntactic way (Podlipniak, 2020), evolved by the means of the Baldwin effect, which means that after cultural invention of pitch hierarchy it was overtaken by genetic control. Regardless of whether it is true or not, the fact that tonal organization of music is prevalent across musical cultures (Mehr et al., 2019) strengthens the view that human proclivity to implicitly learn the rules of pitch distribution in music is a result of the process of canalization. After all, the prevalence of tonality among musical cultures across the world, which are enormously diversified in respect of other musical traits, indicates that pitch syntax must have become a stable musical feature. It has been either culturally transmitted from an ancient common ancestral culture or it develops independently thanks to some genetic proclivities. The same reason can explain the universality of hierarchical organization of musical rhythm. As a result, musical syntax usually consists of pitch and rhythm hierarchies. Therefore, both explanations are consistent with the claim that the use of a pitch-rhythm framework for musical syntax is an example of a canalized behavioral trait of *Homo sapiens*. To some extent musical syntax is like the grammar of a mother tongue. As the tacit knowledge of grammar restricts the possible word flexion and order in sentences, the musical syntax puts constraints on musical expressions. In other words, musical syntax answers the question when and what kind of pitch is acceptable. However, there is not only one answer to this question. Moreover, the permanently changing social environment means that the aesthetic preferences are also changing. As a result, different tunes may bring the house down in different times. Having many possible melodic variants that are congruent with the syntactic rules of a particular music style, and that can simultaneously satisfy the aesthetic preferences of a given social group opens space for creativity. This kind of creativity is often called "combinational" (Boden, 2004, p. 3) since the innovation represents a new combination of sounds within a framework of the present syntactic rules. Sometimes, however, an individual is able to create sound sequences that surpass the existing rules and to implement new ones. This kind of creativity is called "exploratory" (Boden, 2004, p. 4) as it explores formerly unknown rules of organization. It is possible that the neurological structures that are not music-specific, such as the default mode network, play some role in such innovative thinking. In both cases, however, the creative individuals must be familiar with the aforesaid implicit knowledge which means that they are constrained by the existing implicitly learned rules. After all, changing the rules necessitates the knowledge of what has changed. The new rules, if socially accepted, become implicitly learned by the next generations of listeners until new innovative rules are created and socially accepted. This endless process is a good example of cultural evolution which runs faster than gene-culture coevolution. However, in the long run, even in a fast-changing culture, some features can become canalized. Canalization opens the coevolutionary concatenation of events. The example of a ubiquitous syntactic pitch-rhythm framework of music suggests that human musicality has become a subject of canalization. However, although musical creativity, being a force that leads to musical change, acts against canalization it is at the same time a product of it. Without the canalized perceptual traits such as rhythm measures, pitch intervals, etc. musical creativity would be devoid of a well-defined space.

CONCLUSION

According to the presented view, musical creativity did not only appear in the course of hominin evolution but also became a driving force of the gene-culture coevolution of human musicality. Being an inseparable part of a cultural plastic change, creativity in the domain of pitch and rhythm gave diversity which became the subjects of cultural selection. Only such circumstances opened space for the canalization of pitch intervals and rhythm measures as discrete musical units that dominated human musicality for millennia. Moreover, since the default experience of musical pitch and rhythm is preconceptual, their appearance most probably preceded the evolution of the conceptual mind. This suggests that creativity in the domain of musical pitch and rhythm represents a domain specific ability in contrast to creativity that operates in the conceptual mind. Of course, it does not exclude the possibility that people can be creative in music using conceptual resources. This is especially possible as part of Webster's aforementioned creative thinking process at the level of convergent thoughts (Webster, 2002). After all, professional musicians are able to learn pitch intervals and rhythm schemes as precise defined concepts and categorically perceived entities. This task necessitates, however, strenuous and time-consuming learning, suggesting the crucial role of phenotypic plasticity in this process. Moreover, musical phrases can be the source of associations that can be used in creative composing which can be consciously incorporated into analytical thinking leading to aesthetic decisions. Nevertheless, music-specific creativity operates mainly in the realm of tonal music, whereas general creativity can be especially desirable in "sound arts" and other kinds of music that abandon rhythm and pitch syntaxes.

The proposed view that musical creativity is linked to gene-culture coevolution emphasizes the important role of individual invention in the process of generating cultural variability. After all, an increasing number of song variants achieved by individuals' creativity extends the scope of a cultural environment to be selected. Independent of this variability the social success of creative individuals could facilitate natural selection of those individuals whose creativity meets the social requirements. As a result, over a long period of time human musicality appears to be a permanently changing capacity influenced by both social aesthetic trends and our predispositions to be creative in the domain of music. This implies that musical creativity is a part of human nature which means that musical creative thoughts should be achievable by the majority of people. Although the proposed evolutionary scenario is speculative there are some possible areas of study which can explore its implications. The search for genetic predispositions of musicality is the most promising scope of research in this respect. Another area research that can help to answer the question about the role of plasticity and canalization in evolution musical creativity is the neuroscience of music. The recognition of the limits of neural plasticity related to the processing of musical pitch and rhythm could shed some light on the specificity of creativity in the domain of music.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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REFERENCES

Ackermann, H., Hage, S. R., and Ziegler, W. (2014). Brain mechanisms of acoustic communication in humans and nonhuman primates: An evolutionary perspective. *Behav. Brain Sci.* 37, 529–546. doi: 10.1017/S0140525X13003099

Agawu, V. K. (1987). The rhythmic structure of West African music. *J. Musicol.* 5, 400–418. doi: 10.2307/763699

Baldwin, J. M. (1896a). A new factor in evolution. *Am. Nat.* 30, 441–451. doi: 10.1086/276408

Baldwin, J. M. (1896b). A new factor in evolution (Continued). *Am. Nat.* 30, 536–553. doi: 10.1086/276428

Bannan, N. (2008). Language out of music: the four dimensions of vocal learning. *Aust. J. Anthropol.* 19, 272–293. doi: 10.1111/j.1835-9310.2008.tb00354.x

Bannan, N. (2012). "Harmony and its role in human evolution," in *Music, Language, and Human Evolution*, ed. N. Bannan (Oxford: Oxford University Press), 288–340. doi: 10.1093/acprof:osobl/9780199227341.003.0012

Bashwiner, D. M. (2018). "The neuroscience of musical creativity," in *The Cambridge Handbook of the Neuroscience of Creativity*, eds R. E. Jung and O.

Vartanian (New York, NY: Cambridge University Press), 495–516. doi: 10.1017/9781316556238.029

Bashwiner, D. M., Wertz, C. J., Flores, R. A., and Jung, R. E. (2016). Musical creativity "Revealed" in brain structure: interplay between motor, default mode, and limbic networks. *Sci. Rep.* 6:20482. doi: 10.1038/srep20482

Bharucha, J. J., Curtis, M., and Paroo, K. (2011). "Musical communication as alignment of brain states," in *Language and Music as Cognitive Systems*, eds P. Rebuschat, M. Rohrmeier, J. A. Hawkins, and I. Cross (Oxford, New York: Oxford University Press), 139–155. doi: 10.1093/acprof:oso/9780199553426.003.0016

Bickerton, D. (2009). "Syntax for non-syntacticians A brief primer," in *Biological Foundations and Origin of Syntax*, eds D. Bickerton and E. Szathmáry (Cambridge: The MIT Press), 3–13. doi: 10.7551/mitpress/9780262013567.001.0001

Bickerton, D. (2010). *Adam's Tongue: How Humans Made Language, How Language Made Humans*. New York, NY: Hill and Wang.

Birdsong, D. (2018). Plasticity, variability and age in second language acquisition and bilingualism. *Front. Psychol.* 9:81. doi: 10.3389/fpsyg.2018.00081

Boden, M. A. (2004). *The Creative Mind: Myths and Mechanisms*, 2 Edn. New York, NY: Routledge.

Brandt, A., Gebrian, M., and Slevc, L. R. (2012). Music and early language acquisition. *Front. Psychol.* 3:327. doi: 10.3389/fpsyg.2012.00327

Bregman, A. S. (1990). *Auditory Scene Analysis: The Perceptual Organization of Sound*. London: The MIT Press.

Brockelman, W. Y., and Schilling, D. (1984). Inheritance of stereotyped gibbon calls. *Nature* 312, 634–636. doi: 10.1038/312634a0

Brown, S., and Jordania, J. (2011). Universals in the world's musics. *Psychol. Music* 41, 229–248. doi: 10.1177/0305735611425896

Copeland, N. E. (2019). InMI and its potential originality – musical creativity in composers' minds. *Interdiscip. Stud. Musicol.* 19, 41–52. doi: 10.14746/ism.2019.19.3

Creanza, N., Kolodny, O., and Feldman, M. W. (2017). Cultural evolutionary theory: How culture evolves and why it matters. *Proc. Natl. Acad. Sci. U.S.A.* 114, 7782–7789. doi: 10.1073/pnas.1620732114

Deacon, T. W. (2010). A role for relaxed selection in the evolution of the language capacity. *Proc. Natl. Acad. Sci. U.S.A.* 107, 9000–9006. doi: 10.1073/pnas.0914624107

Deutsch, D. (2019). *Musical Illusions and Phantom Words: How Music and Speech Unlock Mysteries of the Brain*. New York, NY: Oxford University Press, doi: 10.1093/oso/9780190206833.001.0001

Dor, D., and Jablonka, E. (2000). From cultural selection to genetic selection: a framework for the evolution of language. *Selection* 1, 33–56. doi: 10.1556/Select.1.2000.1-3.5

Dor, D., and Jablonka, E. (2001). "How language changed the genes: toward an explicit account of the evolution of language," in *New Essays on the Origin of Language*, eds J. Trabant and S. Ward (Berlin: De Gruyter Mouton), 149–176. doi: 10.1515/9783110849080.149

Dor, D., and Jablonka, E. (2010). "Plasticity and canalization in the evolution of linguistic communication: an evolutionary developmental approach," in *The Evolution of Human Language*, eds R. K. Larson, V. Deprez, and H. Yamakido (Cambridge: Cambridge University Press), 135–147. doi: 10.1017/CBO9780511817755.010

Dunbar, R. I. M. (1996). *Grooming, Gossip, and the Evolution of Language*. London: Harvard University Press.

Fassbender, C. (1996). "Infants' auditory sensitivity towards acoustic parameters of speech and music," in *Musical Beginnings: Origins and Development of Musical Competence*, eds I. Deliège and J. Sloboda (Oxford: Oxford University Press), 56–87. doi: 10.1093/acprof:oso/9780198523321.003.0003

Fedorenko, E., Patel, A., Casasanto, D., Winawer, J., and Gibson, E. (2009). Structural integration in language and music: evidence for a shared system. *Mem. Cognit.* 37, 1–9. doi: 10.3758/MC.37.1.1

Fenk-Oczlon, G. (2017). What vowels can tell us about the evolution of music. *Front. Psychol.* 8:1581. doi: 10.3389/fpsyg.2017.01581

Fitch, W. T. (2015). Four principles of bio-musicology. *Philos. Trans. R. Soc. London B Biol. Sci.* 370, 20140091. doi: 10.1098/rstb.2014.0091

Fitch, W. T., and Jarvis, E. D. (2013). "Birdsong and other animal models for human speech, song, and vocal learning," in *Language, Music and the Brain*, ed. M. A. Arbib (Cambridge: The MIT Press), 499–539.

Friedmann, N., and Rusou, D. (2015). Critical period for first language: the crucial role of language input during the first year of life. *Curr. Opin. Neurobiol.* 35, 27–34. doi: 10.1016/j.conb.2015.06.003

Fusco, G., and Minelli, A. (2010). Phenotypic plasticity in development and evolution: facts and concepts. Introduction. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 365, 547–556. doi: 10.1098/rstb.2009.0267

Geiser, E., Notter, M., and Gabrieli, J. D. E. (2012). A corticostriatal neural system enhances auditory perception through temporal context processing. *J. Neurosci.* 32, 6177–6182. doi: 10.1523/JNEUROSCI.5153-11.2012

Geissmann, T. (2000). "Gibbon songs and human music from an evolutionary perspective," in *The Origins of Music*, eds N. L. Wallin, B. Merker, and S. Brown (London: The MIT Press), 103–123.

Gerbault, P., Liebert, A., Itan, Y., Powell, A., Currat, M., Burger, J., et al. (2011). Evolution of lactase persistence: an example of human niche construction. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 366, 863–877. doi: 10.1098/rstb.2010.0268

Gorzelańczyk, E. J., Podlipniak, P., Walecki, P., Karpiński, M., and Tarnowska, E. (2017). Pitch syntax violations are linked to greater skin conductance changes, relative to Timbral violations – the predictive role of the reward system in perspective of cortico–subcortical loops. *Front. Psychol.* 8:586. doi: 10.3389/fpsyg.2017.00586

Grahn, J. A., and Rowe, J. B. (2009). Feeling the beat: premotor and striatal interactions in musicians and nonmusicians during beat perception. *J. Neurosci.* 29, 7540–7548. doi: 10.1523/JNEUROSCI.2018-08.2009

Grahn, J. A., and Rowe, J. B. (2013). Finding and feeling the musical beat: striatal dissociations between detection and prediction of regularity. *Cereb. Cortex* 23, 913–921. doi: 10.1093/cercor/bhs083

Hagen, E. H., and Bryant, G. A. (2003). Music and dance as a coalition signaling system. *Hum. Nat.* 14, 21–51. doi: 10.1007/s12110-003-1015-z

Hagen, E. H., and Hammerstein, P. (2009). Did Neanderthals and other early humans sing? Seeking the biological roots of music in the territorial advertisements of primates, lions, hyenas, and wolves. *Music. Sci.* 13, 291–320. doi: 10.1177/1029864909013002131

Harwood, D. L. (1976). Universals in music: a perspective from cognitive psychology. *Ethnomusicology* 20, 521–533. doi: 10.2307/851047

Hattori, Y., and Tomonaga, M. (2020). Rhythmic swaying induced by sound in chimpanzees (Pan troglodytes). *Proc. Natl. Acad. Sci. U.S.A.* 117, 936–942. doi: 10.1073/pnas.1910318116

Hattori, Y., Tomonaga, M., and Matsuzawa, T. (2013). Spontaneous synchronized tapping to an auditory rhythm in a chimpanzee. *Sci. Rep.* 3:1566. doi: 10.1038/srep01566

Hattori, Y., Tomonaga, M., and Matsuzawa, T. (2015). Distractor effect of auditory rhythms on self-paced tapping in chimpanzees and humans. *PLoS One* 10:e0130682. doi: 10.1371/journal.pone.0130682

Hauser, M. D. (2000). "The sound and the fury: primate vocalizations as reflections of emotion and thought," in *The origins of music*, eds N. L. Wallin, S. Brown, and B. Merker (Cambridge, MA: The MIT Press), 77–102.

Hauser, M. D., and Konishi, M. (1999). *The Design of Animal Communication*. London: The MIT Press.

Horowitz, S. S. (2012). *The Universal Sense: How Hearing Shapes the Mind*. New York, NY: Bloomsbury.

Huron, D. B. (2006). *Sweet Anticipation: Music and The Psychology of Expectation*. London: The MIT Press.

Jablonka, E., and Lamb, M. J. (2005). *Evolution in Four Dimensions: Genetic, Epigenetic, Behavioral, and Symbolic Variation in the History of Life*. London: MIT Press.

Jackendoff, R. (2009). Parallels and nonparallels between language and music. *Music Percept.* 26, 195–204. doi: 10.1525/mp.2009.26.3.195

Jackendoff, R., and Lerdahl, F. (2006). The capacity for music: what is it, and what's special about it? *Cognition* 100, 33–72. doi: 10.1016/j.cognition.2005.11.005

Jacoby, N., and McDermott, J. H. (2017). Integer ratio priors on musical rhythm revealed cross-culturally by iterated reproduction. *Curr. Biol.* 27, 359–370. doi: 10.1016/j.cub.2016.12.031

Janik, V. M., and Slater, P. J. B. (1997). Vocal learning in mammals. *Adv. Stud. Behav.* 26, 59–99. doi: 10.1016/S0065-3454(08)60377-0

Jarvis, E. D. (2007). Neural systems for vocal learning in birds and humans: a synopsis. *J. Ornithol.* 148, 35–44. doi: 10.1007/s10336-007-0243-0

Jordania, J. (2014). *Tigers, Lions and Humans: History of Rivalry, Conflict, Reverence and Love*. Tibilisi: Logos.

Killin, A. (2016). Rethinking music's status as adaptation versus technology: a niche construction perspective. *Ethnomusicol. Forum* 25, 1–24. doi: 10.1080/17411912.2016.1159141

Killin, A. (2017). Plio-pleistocene foundations of hominin musicality: coevolution of cognition, sociality, and music. *Biol. Theory* 12, 222–235. doi: 10.1007/s13752-017-0274-6

Klein, C., Liem, F., Hänggi, J., Elmer, S., and Jäncke, L. (2016). The "silent" imprint of musical training. *Hum. Brain Mapp.* 37, 536–546. doi: 10.1002/hbm.23045

Krumhansl, C. L. (1990). *Cognitive Foundations of Musical Pitch*. New York: Oxford University Press, doi: 10.1093/acprof:oso/9780195148367.001.0001

Krumhansl, C. L., and Cuddy, L. L. (2010). "A theory of tonal hierarchies in music," in *Music Perception*, eds M. R. Jones, R. R. Fay, and A. N. Popper (London: Springer), 51–87. doi: 10.1007/978-1-4419-6114-3_3

Kunert, R., Willems, R. M., Casasanto, D., Patel, A. D., and Hagoort, P. (2015). Music and language syntax interact in Broca's area: an fMRI study. *PLoS One* 10:e141069. doi: 10.1371/journal.pone.0141069

Laland, K. N. (2008). Exploring gene-culture interactions: Insights from handedness, sexual selection and niche-construction case studies. *Philos. Trans. R. Soc. B Biol. Sci.* 363, 3577–3589. doi: 10.1098/rstb.2008.0132

Laland, K. N. (2017). *Darwin's Unfinished Symphony: How Culture Made the Human Mind*. Princeton, NJ: Princeton University Press.

Leonardi, M., Gerbault, P., Thomas, M. G., and Burger, J. (2012). The evolution of lactase persistence in Europe. A synthesis of archaeological and genetic evidence. *Int. Dairy J.* 22, 88–97. doi: 10.1016/j.idairyj.2011.10.010

Lerdahl, F. (2013). "Musical syntax and its relation to linguistic syntax," in *Language, Music, and the Brain*, ed. M. A. Arbib (London: The MIT Press), 257–272. doi: 10.7551/mitpress/9780262018104.003.0010

Lerdahl, F., and Jackendoff, R. (1983). *A Generative Theory of Tonal Music*. Cambridge: The MIT Press.

Levitin, D. J., Grahn, J. A., and London, J. (2018). The psychology of music: rhythm and movement. *Annu. Rev. Psychol.* 69, 51–75. doi: 10.1146/annurev-psych-122216-011740

Li, P., Legault, J., and Litcofsky, K. A. (2014). Neuroplasticity as a function of second language learning: Anatomical changes in the human brain. *Cortex* 58, 301–324. doi: 10.1016/j.cortex.2014.05.001

Loison, L. (2019). Canalization and genetic assimilation: Reassessing the radicality of the Waddingtonian concept of inheritance of acquired characters. *Semin. Cell Dev. Biol.* 88, 4–13. doi: 10.1016/j.semcdb.2018.05.009

London, J. (2012). Three things linguists need to know about rhythm and time in music. *Empir. Musicol. Rev.* 7, 5–11.

Lumsden, C. J., and Wilson, E. O. (1980). Translation of epigenetic rules of individual behavior into ethnographic patterns. *Proc. Natl. Acad. Sci. U.S.A.* 77, 4382–4386. doi: 10.1073/pnas.77.7.4382

Lumsden, C. J., and Wilson, E. O. (1982). Précis of genes, mind, and culture. *Behav. Brain Sci.* 5, 1–37. doi: 10.1142/5786

McMullen, E., and Saffran, J. R. (2004). Music and language: a developmental comparison. *Music Percept.* 21, 289–311. doi: 10.1525/mp.2004.21.3.289

Mehr, S. A., Singh, M., Knox, D., Ketter, D. M., Pickens-Jones, D., Atwood, S., et al. (2019). Universality and diversity in human song. *Science* 366:eaax0868. doi: 10.1126/science.aax0868

Merker, B. (2000). "Synchronous chorusing and human origins," in *The Origins of Music*, eds N. L. Wallin, B. Merker, and S. Brown (Cambridge, MA: The MIT Press), 315–327.

Merker, B. (2002). Music: the missing Humboldt system. *Music. Sci.* 6, 3–21. doi: 10.1177/102986490200600101

Merker, B. (2005). The conformal motive in birdsong, music, and language: an introduction. *Ann. N. Y. Acad. Sci.* 1060, 17–28. doi: 10.1196/annals.1360.003

Merker, B. (2006). "Layered constraints on the multiple creativities of music," in *Musical Creativity. Multidisciplinary Research in Theory and Practice*, eds I. Deliège and G. A. Wiggins (Hove, NY: Psychology Press of the Taylor & Francis Group), 25–41.

Merker, B. (2009). "Ritual foundations of human uniqueness," in *Communicative musicality. Exploring the Basis of Human Companionship*, eds C. Malloch and S. Trevarthen (Oxford, New York: Oxford University Press), 45–59.

Merker, B. (2012). "The vocal learning constellation," in *Music, Language, and Human Evolution*, ed. N. Bannan (London: Oxford University Press), 215–260. doi: 10.1093/acprof:osobl/9780199227341.003.0009

Mery, F., and Burns, J. G. (2010). Behavioural plasticity: an interaction between evolution and experience. *Evol. Ecol.* 24, 571–583. doi: 10.1007/s10682-009-9336-y

Meyer, M., Elmer, S., and Jäncke, L. (2012). Musical expertise induces neuroplasticity of the planum temporale. *Ann. N. Y. Acad. Sci.* 1252, 116–123. doi: 10.1111/j.1749-6632.2012.06450.x

Mithen, S. J. (2006). *The Singing Neanderthals: The Origins of Music, Language, Mind, and Body*. Cambridge: Harvard University Press.

Mithen, S. J. (2009). The music instinct: the evolutionary basis of musicality. *Ann. N. Y. Acad. Sci.* 1169, 3–12. doi: 10.1111/j.1749-6632.2009.04590.x

Morley, I. (2013). *The Prehistory of Music: Human Evolution, Archaeology, and the Origins of Musicality*. New York: Oxford University Press.

Nettl, B. (2000). "An ethnomusicologist contemplates universals in musical sound and musical culture," in *The Origins of Music*, eds N. L. Wallin, B. Merker, and S. Brown (London: The MIT Press), 463–472.

Norman-Haignere, S., Kanwisher, N. G., and McDermott, J. H. (2015). Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition. *Neuron* 88, 1281–1296. doi: 10.1016/j.neuron.2015.11.035

Parncutt, R. (1994). A perceptual model of pulse salience and metrical accent in musical rhythms. *Music Percept. Interdiscip. J.* 11, 409–464. doi: 10.2307/40285633

Pascual-Leone, A., Amedi, A., Fregni, F., and Merabet, L. B. (2005). The plastic humen brain cortex. *Annu. Rev. Neurosci.* 28, 377–401. doi: 10.1146/annurev.neuro.27.070203.144216

Patel, A. D. (2018). "Music as a transformative technology of the mind: an update," in *The Origins of Musicality*, ed. H. Honing (Cambridge, MA: The MIT Press), 113–126. doi: 10.7551/mitpress/10636.003.0009

Patel, A. D., and Iversen, J. R. (2014). The evolutionary neuroscience of musical beat perception: the Action Simulation for Auditory Prediction (ASAP) hypothesis. *Front. Syst. Neurosci.* 8:57. doi: 10.3389/fnsys.2014.00057

Payne, K. (2000). "The progressively changing songs of humpback whales: a window on the creative process in a wild animal," in *The Origins of Music*, eds N. L. Wallin, B. Merker, and S. Brown (London: MIT Press), 135–150.

Perani, D., Saccuman, M. C., Scifo, P., Spada, D., Andreolli, G., Rovelli, R., et al. (2010). Functional specializations for music processing in the human newborn brain. *Proc. Natl. Acad. Sci. U.S.A.* 107, 4758–4763. doi: 10.1073/pnas.0909074107

Peretz, I. (2006). The nature of music from a biological perspective. *Cognition* 100, 1–32. doi: 10.1016/j.cognition.2005.11.004

Perrin, E., and Venance, L. (2019). Bridging the gap between striatal plasticity and learning. *Curr. Opin. Neurobiol.* 54, 104–112. doi: 10.1016/j.conb.2018.09.007

Perruchet, P., and Poulin-Charronnat, B. (2013). Challenging prior evidence for a shared syntactic processor for language and music. *Psychon. Bull. Rev.* 20, 310–317. doi: 10.3758/s13423-012-0344-5

Pigliucci, M. (2001). "Characters and environments," in *The Character Concept in Evolutionary Biology*, ed. G. P. Wagner (San Diego, CA: Academic Press), 363–388. doi: 10.1016/B978-012730055-9/50028-8

Pinker, S., and Jackendoff, R. (2005). The faculty of language: what's special about it? *Cognition* 95, 201–236. doi: 10.1016/j.cognition.2004.08.004

Podlipniak, P. (2015). "The origin of music and the Baldwin effect," in *Proceedings of Ninth Triennial Conference of the European Society for the Cognitive Sciences of Music*, eds J. Ginsborg, A. Lamont, and S. Bramley (Manchester: Royal Northern College of Music), 671–677.

Podlipniak, P. (2016). The evolutionary origin of pitch centre recognition. *Psychol. Music* 44, 527–543. doi: 10.1177/0305735615577249

Podlipniak, P. (2017). The role of the Baldwin effect in the evolution of human musicality. *Front. Neurosci.* 11:542. doi: 10.3389/fnins.2017.00542

Podlipniak, P. (2020). Pitch syntax as an evolutionary prelingual innovation. *Music. Sci.* doi: 10.1177/1029864920941551 [Epub ahead of print],

Rakowski, A. (1999). Perceptual dimensions of pitch and their appearance in the phonological system of music. *Music. Sci.* 3, 23–39. doi: 10.1177/102986499900300102

Rakowski, A. (2009). The domain of pitch in music. *Arch. Acoust.* 34, 429–443.

Repp, B. H. (2007). Hearing a melody in different ways: Multistability of metrical interpretation, reflected in rate limits of sensorimotor synchronization. *Cognition* 102, 434–454. doi: 10.1016/j.cognition.2006.02.003

Reybrouck, M. (2006). "Musical creativity between symbolic modelling and perceptual constraints. The role of adaptive behaviour and epistemic autonomy," in *Musical Creativity. Multidisciplinary Research in Theory and Practice*, eds I. Deliège and G. A. Wiggins (Hove: Psychology Press of the Taylor & Francis Group), 43–59.

Roederer, J. G. (1984). The search for a survival value of music. *Music Percept. Interdiscip. J.* 1, 350–356. doi: 10.2307/40285265

Rogalsky, C., Rong, F., Saberi, K., and Hickok, G. (2011). Functional anatomy of language and music perception: temporal and structural factors investigated using functional magnetic resonance imaging. *J. Neurosci.* 31, 3843–3852. doi: 10.1523/JNEUROSCI.4515-10.2011

Rothenberg, D., Roeske, T. C., Voss, H. U., Naguib, M., and Tchernichovski, O. (2014). Investigation of musicality in birdsong. *Hear. Res.* 308, 71–83. doi: 10.1016/j.heares.2013.08.016

Savage, P. E. (2019). Cultural evolution of music. *Palgrave Commun.* 5, 1–12. doi: 10.1057/s41599-019-0221-1

Savage, P. E., Brown, S., Sakai, E., and Currie, T. E. (2015). Statistical universals reveal the structures and functions of human music. *Proc. Natl. Acad. Sci. U.S.A.* 112, 8987–8992. doi: 10.1073/pnas.1414495112

Savage, P. E., Loui, P., Tarr, B., Schachner, A., Glowacki, L., Mithen, S., et al. (2020). Music as a coevolved system for social bonding. *Behav. Brain Sci.* doi: 10.1017/S0140525X20000333 [Epub ahead of print],

Scheumann, M., Hasting, A. S., Kotz, S. A., and Zimmermann, E. (2014). The voice of emotion across species: how do human listeners recognize animals' affective states? *PLoS One* 9:e91192. doi: 10.1371/journal.pone.0091192

Surmeier, D. J., Plotkin, J., and Shen, W. (2009). Dopamine and synaptic plasticity in dorsal striatal circuits controlling action selection. *Curr. Opin. Neurobiol.* 19, 621–628. doi: 10.1016/j.conb.2009.10.003

Sznajder, B., Sabelis, M. W., and Egas, M. (2012). How adaptive learning affects evolution: reviewing theory on the baldwin effect. *Evol. Biol.* 39, 301–310. doi: 10.1007/s11692-011-9155-2

Takahashi, K. H. (2019). Multiple modes of canalization: links between genetic, environmental canalizations and developmental stability, and their trait-specificity. *Semin. Cell Dev. Biol.* 88, 14–20. doi: 10.1016/j.semcdb.2018.05.018

Tillmann, B., Bharucha, J. J., and Bigand, E. (2000). Implicit learning of tonality: a self-organizing approach. *Psychol. Rev.* 107, 885–913. doi: 10.1037/0033-295X.107.4.885

Tinbergen, N. (1963). On aims and methods of Ethology. *Z. Tierpsychol.* 20, 410–433. doi: 10.1111/j.1439-0310.1963.tb01161.x

Toiviainen, P., Luck, G., and Thompson, M. R. (2010). Embodied meter: hierarchical eigenmodes in music-induced movement. *Music Percept.* 28, 59–70. doi: 10.1525/mp.2010.28.1.59

Tomasello, M. (1999). *The Cultural Origins of Human Cognition*. Harvard: Harvard University Press.

Trainor, L. J. (2005). Are there critical periods for musical development? *Dev. Psychobiol.* 46, 262–278. doi: 10.1002/dev.20059

Trehub, S. E. (2015). Cross-cultural convergence of musical features. *Proc. Natl. Acad. Sci. U.S.A.* 112, 8809–8810. doi: 10.1073/pnas.1510724112

Waddington, C. H. (1942). Canalization of development and the inheritance of acquired characters. *Nature* 150, 563–565. doi: 10.1038/150563a0

Watson, S. K., Townsend, S. W., Schel, A. M., Wilke, C., Wallace, E. K., Cheng, L., et al. (2015). Vocal learning in the functionally referential food grunts of chimpanzees. *Curr. Biol.* 25, 495–499. doi: 10.1016/j.cub.2014.12.032

Webster, P. R. (1990). Creativity as creative thinking. *Music Educ. J.* 76, 22–28. doi: 10.2307/3401073

Webster, P. R. (2002). "Creative thinking in music: advancing a model," in *Creativity and Music Education*, eds T. Sullivan and L. Willingham (Toronto, ON: Canadian Music Educators' Association), 16–34.

West-Eberhard, M. J. (2005). Developmental plasticity and the origin of species differences. *Proc. Natl. Acad. Sci. U.S.A.* 102, 6543–6549. doi: 10.1073/pnas.0501844102

White, E., Hutka, S., Williams, L., and Moreno, S. (2013). Learning, neural plasticity and sensitive periods: implications for language acquisition, music training and transfer across the lifespan. *Front. Syst. Neurosci.* 7:90. doi: 10.3389/fnsys.2013.00090

Wilson, E. O. (1978). *On Human Nature*. Cambridge, MA: Harvard University Press.

Wright, A. A., Shyan, M. R., and Jitsumori, M. (1990). Auditory same/different concept learning by monkeys. *Anim. Learn. Behav.* 18, 287–294. doi: 10.3758/BF03205288

Zimmermann, E., Leliveld, L., and Schehka, S. (2013). "Toward the evolutionary roots of affective prosody in human acoustic communication: A comparative approach to mammalian voices," in *Evolution of Emotional Communication: from Sounds in Nonhuman Mammals to Speech and Music in Man*, eds E. Altenmüller, S. Schmidt, and E. Zimmermann (Oxford: Oxford University Press), 116–132.

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The Experimental Composition Improvisation Continua Model: A Tool for Musical Analysis

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Among improvisers and composers today there is a resurgence of interest in experimental music (EM) practices that welcome contingency; engaging with unforeseen circumstances as an essential component of the music-making process, and a means to sonic discovery. I propose the *Experimental Composition Improvisation Continua* (ECIC) as a model with which to better understand these experimental musical works. The historical Experimental Music movement of the 1950s and 60s is briefly revisited, and the jazz tradition included as an essential protagonist; both being important historical movements leading to the formulation of ideas around contingent musical practices. The ECIC model is outlined as providing a means to observe the interactions and continua between composition and improvisation on the one hand and more or less experimentally conceived music on the other. This model is applied as an investigative and comparative tool to three distinctive works in order to illuminate the presence or otherwise of various experimental interactions within them. The works are: "Spiral Staircase" – a composition by written by Satoko Fujii in late 2007, John Cage's *4′33″*, and a performance of "My Favorite Things" by the John Coltrane Quartet. Further possible applications of the ECIC are suggested in the conclusion.

Keywords: music improvisation, music composition, composition-improvisation continuum, contingency, experimental music, musical creativity, music performance

INTRODUCTION

Among improvising musicians today, and composers who are writing for improvisers, there is a burgeoning interest in experimental music (EM) practices that transcend idiom and musical tradition (Beins et al., 2011; Cox and Warner, 2013; Gottschalk, 2016). I am referring to music making that actively engages with unforeseen circumstances and outcomes as an essential component of the work (Nyman, 1999, 1–30).[1] Although often operating on the fringes of musical communities, the enormous output of this work, *via* concerts and recordings, has been reviewed widely by a host of music magazines and on-line blogs. At the same time,

[1]It should be noted that in this article, I am referring the term "experimental music," and what centrally defines it, as outlined by its historically situated practitioners in the Experimental Music movement in the 1950s and 60s.

with a few notable exceptions,[2] little has been documented or analyzed in contemporary scholarly writing that examines the field in a holistic manner or takes into account either its breadth of practice or its effective cross-genre artistic contribution. This article investigates the active commonalities and convergences in experimental compositional and improvisational work *across* stylistic delineations. Connections are highlighted between the action of chance and indeterminism in improvisation, and its associated relationships with composition and a model introduced as an investigative tool. The environment of contingency, chance, and indeterminism is proposed as a catalyst for new ideas, new interactions, new sounds, and new perceptions. What I have termed the *Experimental Composition Improvisation Continua* (ECIC) view the relationships between the experimental, compositional, and improvisational elements in music making as being in flux: flowing between differing degrees of engagement (Spence, 2018, 2020). The ECIC model offered in this article is a qualitative tool with which to investigate and compare experimental, compositional, and improvisational work – both historical and contemporary – beyond genre, and to identify the contribution of elements within this work to unforeseen outcomes.[3] The model can be used to compare the musical actions and outcomes of composers, performers, and the musical environment, both within a work and across works.

I take the Experimental Music Movement in the 1950s and 60s as a starting point for the crystallization of "beyond idiom" ideas around contingency and chance. I also acknowledge the now well-documented debt that EM owes to jazz music as highlighted in the writings of Lewis (1996, 2009), Radano (2009), Kim (2012), and others.

AIMS

In this article, I identify the nature and activity of experimentalism, composition, and improvisation in music, and the relationships and continua between them and across musical style. I propose the ECIC as an investigative and comparative tool with which to study these elements in experimental music and apply this tool to "Spiral Staircase," a piece performed by the Satoko Fujii Quartet, in order to demonstrate its application. Additionally, I suggest further applications of the ECIC tool and use two well-known examples: the composition *4′33″* by John Cage, and a recorded performance of "My Favorite Things" by John Coltrane in the way of demonstration (Coltrane, 2007).

The questions this article investigates are:

- What characterizes "Experimental Music," "Composition," and "Improvisation," and what are the relationships and continua between them?
- How can these elements be addressed in combination in an investigative tool for experimental music?
- How can the ECIC model be practically utilized to investigate and compare interactions and positionings between experimentalism, composition, and improvisation in live and recorded performance contexts, and also as a means to reflect on pre-existing – for instance compositional – musical processes?

LITERATURE REVIEW: BACKGROUND AND ECIC RELATIONSHIPS

Experimental Music

The Experimental Music (EM) movement was a development within American Art music that was formalized in New York between 1950 and 1951, through the work of composers John Cage, Earle Brown, Morton Feldman, Christian Wolff, and others. These composers explained the focus of EM as being concerned with sound for its own sake, free from historical and traditional associations. They investigated new relationships between sonorities by utilizing processes that caused or allowed accidents, randomness, illusions, or problems, to be negotiated by the composer and/or the performer and/or the audience. Morton Feldman says of this, "only by 'unfixing' the elements traditionally used to construct a piece of music could the sounds exist in themselves – not as symbols, or memories which were memories of other music to begin with" (Feldman and Friedman, 2000, 35). When publicly introducing the term in 1955, Cage said of EM "the word 'experimental' is apt, providing it is understood not as descriptive of an act to be later judged in terms of success and failure, but simply as of an act the outcome of which is unknown" (Cage, 2010, 13). In the African American improvising community, the search for new sound through chance, indeterminism, and contingent process was being explored concurrently, resulting in the "Free Jazz" movement which emerged in the mid-1950s (Jost, 1994; Lewis, 2009). Sun Ra, Ornette Coleman, Cecil Taylor, John Coltrane, Archie Shepp, Muhal Richard Abrams, and others pioneered a new and exploratory form of improvising that engaged with chance elements through practices and processes such as group improvisation, open unstructured forms, and freedom of choice with regard to tonality. The democratic, non-hierarchical aspects of group interaction, the relationship to motoric rhythm, and the focus on personal narrative marked this music as a distinctive expression of experimentalism. Musician and academic George Lewis terms this expression as *Afrological* experimentalism (Lewis, 1996). Lewis also contends that the bebop development in jazz music, which unfolded in the 1940s, was at its core experimental in nature. He says of

[2]Two examples of a broad overview of contemporary experimental work are *Experimental Music Since 1970* (Gottschalk, 2016), and *Audio Culture* (Cox and Warner, 2013). Piekut also investigates cross-genre; cross-culture experimentalism in *Tomorrow is the Question* (2014).

[3]In this article, I take "work" to also include the sounds that result due to performance, which may be linked to pre-existing compositional material ("scores"). As Max Neuhaus states "These pieces [scores] are not musical products, they are meant to be activities" (Goehr, 2007, 244). Goehr points out that the concept of the musical work is an open one and has been adopted and adapted in ways that "extend the concept's employment" to refer to musical styles and cultural settings well beyond its classical music origins and including improvisation (255). Benson states "what we call a 'work' might better be thought of as a developing structure that arises from the activity of music making" (2003, 147).

the relationship between EM and improvisation "indeterminacy could well be not a successor to improvisation but a subset of it" (1996, 229). In other words, Lewis is saying that the EM and jazz traditions have direct links *via* the processes and practices of improvisation. However, at the time, these links were not clearly established. Lewis (1996, 222) describes what he sees as a deliberately manufactured divide between Afrological and *Eurological* experimentalism saying that Eurological experimental "composers such as Cage and Feldman located their work as an integral part of the sociomusical art world that explicitly bonded with the intellectual and music traditions of Europe," and that there was "an ongoing narrative of dismissal, on the part of many of these [Eurological] composers, of the tenets of African-American improvisative forms" (216).[4] While John Cage was outspoken regarding his suspicion of the connection between jazz music and experimentalism, other experimental music composers, such as Earle Brown, Terry Riley, and La Monte Young recognized the connections and, to some extent, acknowledged them in their practice (These three composers all had experience as jazz performers prior to or early in their careers, with Riley and La Monte Young continuing to apply their improvisatory skills in their EM practice).[5] The range of experimental practices and processes that were investigated in the 1950s and 60s – both within Jazz and the Experimental Music movement – in America and Europe included: indeterminism of pitch (and timbre) and time,[6] graphic scores, instrumental preparations, Musique Concrète, and other "acousmatic" practices (Schaeffer, 1966; translated, 2017, 64–69), utilizing electronic sound recording and producing media, sound "theater" (see, for instance, the work of the art movement Fluxus, in Nyman, 1999, 72–88), solo and group improvisation (guided and unguided), and minimalism (acoustic and electronic).[7] These practices continue by in large to be those that are being investigated today, albeit with updated technological tools. Books such as *Audio Culture* (Cox and Warner, 2013) document the adaptation and ongoing development of experimental musical practices and processes, and a range of books outline experimental work in specific locations, "scenes," and cultures (Plourde, 2008; Saunders, 2009; Beins et al., 2011; Piekut, 2014; Toop, 2016). Enduring experimental musical expressions are emerging within and across classical/art music, jazz, rock, folk-musics, free improvisation, sound art, electro-acoustic music, noise music, and the plethora of genres and sub genres that categorize contemporary music. These works are proving protectionist debates regarding experimentalism – such as those regarding process, genre, style, and music culture – to be irrelevant.[8] As a term "experimental music," like many category terms in music (such as "classical music," or "jazz"), is somewhat problematic. While it was first used to describe a particular development in American classical music, it continues to be used as a category description and, as such, has attracted some criticism and semantic deviation. Landy (1991, 6), for example, has argued that in his view "purposelessness" is stated by EM musicians as one of their intentions, and that "any good definition of *experiment* shows that purposelessness is by no means an experimental goal." Joanne Demers aligns with a more recent popularist view of equating experimental music with the avant-garde, as a "series of unusual practices whose strangeness stands out in relation to whatever the mainstream happens to be" (Demers, 2010, 7). This is a view detached from connections with the historical EM movement and its essential link with contingency, chance, or the "unknown." It is my contention that the historically situated term "experimental music" remains a useful and relevant descriptor for an approach to music-making across all styles that welcomes contingency in order to enable a distinctive body of work on the composition-improvisation continuum. The assertion of this research is that contemporary trends in ECIC practice are strong and effective, and yield surprising, provocative, and creative results.[9] As Gottschalk (2016, 1) says when discussing a contemporary definition of experimental music it "is challenging to pin down because it is not a [one] school or a trend or even an aesthetic. It is, instead a position – of openness, of inquiry, of uncertainty, and of discovery."[10]

The Relationship Between Improvisation and Composition

In recent years, scholars have investigated more thoroughly the relationship between the processes and outcomes of improvisation, and those of composition. Models researched include those of temporal perception (Sarath, 1996), potentiality

[4]Since Lewis, McMullen has suggested "Asialogical" as a further socio-cultural musical delineation in improvised music (2003, cited in Borgo, 2002, 171).

[5]For background on Brown and jazz, see Yaffé (2007, 289-290). For Riley see Duckworth (1995, 266), and La Monte Young see Duckworth (1995, 210).

[6]*Indeterminism* is defined by the *Oxford Dictionary* as "the doctrine that not all events are determined by antecedent causes" (Stevenson, 2010). In a musical setting, indeterminism can be engaged with by composers, performers, and the audience with the resultant outcome determined by the in-the-moment decisions made by the participants in direct relationship to the contingencies of their environment. *Performer indeterminism* entails offering the performer(s) individual choices, usually within certain constraints. For instance, at a certain point in time, the performer chooses freely from a (possibly pre-determined) range of pitch or timbre options (indeterminism of pitch and timbre), or alternatively plays a set order of pitches (or timbres) at a time of their choosing and with any tempo within a (possibly pre-determined) span of time (indeterminism of time).

[7]The term "acousmatic" was employed by Musique Concrète pioneer, Pierre Schaeffer, to support his concept of 'sound objects' – sounds perceived independently of their "methods of production and transmission," sounds heard as unique entities (Schaeffer, 2017, 64).

[8]An example of one such debate between the London free improvisation scene, and the "Reductionists" (or New London Silence) regarding gesture in experimental music can be found in Bell (2005, 32-39).

[9]I use the term "practice" here to refer to a musician's mode of operation, for example, a "field-recording" artist or a "minimalist jazz" composer and improviser.

[10]For the purposes of this research, I am referring to the following definitions taken from the Oxford English Dictionary: "Improvisation, n.: The action or fact of composing or performing music, poetry, drama, etc., spontaneously, or without preparation; this method of performance" (Oxford English Dictionary Online 2020). "Contingency, n.: The befalling or occurrence of anything without preordination, chance, fortuitousness. …The quality or condition of being subject to chance and change, or of being at the mercy of accidents" (2020).

(Agamben, as outlined in Lexer, 2010),[11] equivalence (Rink, 1993; Nettl and Russell, 1998), continuity (Alperson, 1984), complementarity (Siepmann, 2010), interpenetration (Hamilton, 2000), process as product (Sawyer, 2000), and certitude (Peters, 2012). Recent handbooks and readers on the subject include Piekut and Lewis (2016) and Hamilton and Pearson (2020). These musicological, ethnomusicological, psychological, and philosophical studies have provided a greater understanding of the environmental, cognitive, and creative networks involved in improvisation, and the interrelationships between different strata of thought and resulting actions. As a consequence improvisation is now better positioned to be regarded as a complex and malleable process – far beyond a simple "action/reaction" (my words) or cause and response environment – and as an effective expression of composition. Improvisation is slowly and belatedly gaining equal status alongside the score in Western Art music, perhaps, previously delineated due to "the [historical] great divide between low culture and high culture" (Piekut and Lewis, 2016, 5). The contribution of studies by Berliner (1994), Bazzana (1997), Benson (2003), Goehr (2007), and Small (2011), and others, has helped to establish a focus on the importance of the performer and the performance, and redress the cultural value imbalance between the composer and the performer. Benson illuminates the collaboration involved in music making stating "if performers are essentially improvisers, then authorship becomes more complex. That is not to deny composers their respective place as 'authors'… but it is to acknowledge that their authorship is really a coauthorship, both with those who have gone before and those who come after" (126). Regarding the in-real-time art of improvisation, Hamilton (2007, 213) argues that "improvisation and composition are interpenetrating opposites – that is, features which appear definitive of one are found in the other also." According to ethnomusicologist Bruno Nettl "musics in the oral tradition do not make the distinction between composition and performance which the concept of improvisation implies" (1998, 11). For Nettl (1974, 6), "the juxtaposing of composition and improvisation as fundamentally different processes is false, […] the two are part of the same idea." Hamilton (2000, 171) agrees and argues further that such works occupy a continuum and "there is in important respects a fluid contrast between a composed work and an improvisation. Their exemplars stand in a continuum, and 'improvisation' and 'composition' denote ideal types or interpenetrating opposites." Both Hamilton and Nettl promote the concept of the composition-improvisation continuum, which allows an infinite range of possible positions between the "ideal types" of the premeditated (and notated) and the immediate (in-the-moment, performed). As an example, composer and improviser Pauline Oliveros refers to improvisation as "speeded-up composition" (Duckworth, 1995, 166). While this may be a prevalent idea among some improvisers, it fails to take into account the unavoidable incidents or accidents, which occur in the moment of performance, and which can and do change the outcome, even if only negligibly.

The Relationship Between Improvisation and Experimentalism

As mentioned earlier, Lewis has done much to uncover the fundamental interrelationship between improvisation and experimentalism (for example, 1996; 2009). Clearly from the outset, there has been interpenetration of process and outcome in music-making activities described by these categories. In the EM movement, improvisational potential first appeared under the guise of "indeterminism." Feldman's score *Projection I* (1950) is an early example of this "open form" type of work. The score is written graphically as a series of boxes and symbols which offer various choices to the performer regarding pitch, playing technique, and duration. This score cannot be interpreted literally and consequently relies on realization by the performer and the opportunity for this to occur in real time (Welsh, 1996). Brown refers to this in-real-time realization potential as "creative ambiguity" (Gresser, 2007, 377). A good example is his early graphic score *December 1952*, a page of horizontal and vertical lines to be performed by any number of instrumentalists, which can be interpreted from any orientation and in any manner that the performer(s) choos(es).[12] Wolff has had a more openly disclosed relationship between experimentalism and improvisation. He favors "surprise," "disruption," and "provocation," and seeks to ensure that a performer's improvised contribution to the work does not follow "habitual techniques." His scores, such as *Duo for Pianists I* (1957), "rely upon the consequences of intentional and non-intended sounds in the performance moment, and the unpredictabilities of ensemble playing" (Thomas and Payne, 2020, 29). Contemporary texts that have investigated the interpenetrations, commonalities, and the continuum between improvisation and experimentalism – both within and also across genre – are by Beins et al. (2011), Piekut (2014), Gottschalk (2016), and DiPiero (2018). Gottschalk, Beins et al., and DiPiero investigate the range, nature, and application of the collaborative process in an indeterminate environment. As Gottschalk (2016, 188) states regarding contingent music-making: "interaction, improvisation, and indeterminancy, these three terms are not interchangeable, but they share a common center: the unknown." DiPiero (2018, 2–3) explains contingency as "an umbrella term for events that either were or will be decided according to some non-linear causality, a term that is cleaved in half depending on where in a temporal process one chooses

[11]Lexer says of potentiality in improvisation "This potential is embedded and constituted within the relationship between the performer and the instrument. Thus, it can be argued that the performer and instrument form an intrinsic unit within which previously acquired skills, positive and negative experiences, and intuitively felt possibilities and limitations are manifested through the performer's personality, motivation, and creativity. This highly complex constellation of human imagination and instrumental possibilities is conceptualized within a potentiality space: A space populated with potential approaches, processes, and responses" (2010, 42).

[12]Brown had a vexed relationship with indeterminism. Over the course of his composition career, he moved away from unrestricted open form works in order to try to preserve what he understood as their identity (Gresser, 2007). Cage similarly sought to restrict interpretive scope and maintain artistic control by working closely with the same performers such as the pianist David Tudor, who essentially became a co-composer with Cage (Holzaepfel, 2001).

to look" and says "contingency invites us to consider every improvisation as non-trivially different – a constellation of openings and closures both, in a singular arrangement."

In *Tomorrow is the Question* of Piekut (2014) – while not overtly focused on improvisation – explores the development of experimentalism and its various relationships with improvisation in "unexamined" music scenes and cultures, such as music practices in Japan, Cuba, and Bali in the 1960s and 70s, and the stylistic "pluralism" evident in the New York Downtown scene in the 1970s and 80s which saw experimentalism "art music, improvised music, and rock" converge (78). In *Echtzeitmusik Berlin: Selbstbestimmung einer Szene*, Beins et al. (2011) interview composers and improvisers in Berlin and uncover a range of attitudes and approaches toward composition, improvisation, collaboration, and the experimental. Philosophical positions adopted by some result in questions regarding the distinctions between these terms, and the existence or otherwise of contingency and chance within the real-time music making process. These differing points of view highlight the relativity of continua between experimentalism, composition, and improvisation – continua that are recalibrated according to individual aesthetic outlook. It is important to note that improvisation and experimentalism are not necessarily part of the same idea. If a work is more improvisational it may not necessarily be more contingent or experimental. It could be argued that *some* improvisation – such as that which takes place within repertory improvisational styles; perhaps, in some iterations of Indian music or some expressions of jazz music – is so formulated and imitative as to be non-experimental. In these situations, music-making may take place in a highly controlled environment that deliberately limits engagement with contingency, chance, and indeterminism. Similarly some contemporary, adventurous, and non-mainstream work, such as that which Demers describes, may feature neither engagement with improvisation, nor experimentalism. Additionally contingency, indeterminism, chance, or experimentalism might be engaged with by the composer in the process of the composition of a work, but not in its performance. Priest (2013) and Voegelin (2014) expand the notion of improvisation and the associated mental constructs and outcomes in experimentalism to include the audience. Both note that an indeterminate work may offer a range of perceptual possibilities to the perceivers, such that they complete or realize the work through in-the-moment choices made in hearing. Voegelin (2014, 28) draws on the Phenomenological theories of Merleau-Ponty and postulates a "phenomenological possibilism," that exists in the apprehension of ambiguous sound art works, as "a plurality of actual, possible, and impossible sonic worlds that we can all inhabit in listening" (14). Though not described as such, this in-the-moment aural constitution of the work by the listener is essentially an improvisatory act: a decision or set of decisions made in real time, and contingent on circumstance, that leads either consciously or unconsciously to a perceptual outcome. Consequently, it can be observed that the relationship between experimentalism, composition, and improvisation (ECIC) operates not just in the processes of the physical construction of the musical work but in its apprehension. McAdams (1984, 319) states that "perceiving is an act of composition." As has been discussed composing in-the-moment or in-real-time is an act of improvisation.

Priest (2013, 22) describes a certain sort of aural "unfocussing" that contemporary urban society is trained in: "the unconsciously acquired habits of listening away and underhearing music," and notes how this has been manipulated in experimental music, saying "certain contemporary experimental compositions exploit the drifts and digressions of distraction in a way that paradoxically draws attention to the 'black noise' and 'allure' radiating from musical sounds that have become something to be 'unfocussed on'" (23). Priest here is describing a form of engagement in which the composer and/or performers and the audience (or perceivers) formulate a musical result based on a contingent listening environment: a result that can be different for each listening subject involved.

The Relationship Between the Environment and Contingency

The relationship of audience and environment to contingency was sensationally publicized at the premiere of Cage's *4′:33″* in which the perceptions of the audience and the sounds of the environment were revealed as being under scrutiny, rather than the sounds being made by the performer (1952, see Nyman, 1999, 11). In the 1960s, the Minimalist music extension of EM, as developed by La Monte Young, Reich, Riley, Glass, and others, exploited the environmental context and the perceptions of the audience by directly – or by process – manipulating sounds in the space in which they were activated, thus enabling sonic illusions and psychoacoustic effects. Steve Reich referred to these effects as sonic "by-products" saying

> "These mysteries are the impersonal, unintended, psychoacoustic by-products of the intended process. These might include sub-melodies heard within repeated melodic patterns, stereophonic effects due to listener location, slight irregularities in performance, harmonics, difference tones, and so on" (Reich and Hillier, 2004, 35).

The enabling of perceptual possibilities, and the contingencies of environmental interaction, continue to be of interest and offer potential for sonic experimentalists today.

Experimental Techniques and Processes in Composition, Performance, and Perception

An important aspect of experimental music investigation has been the recognition that contingency and chance act on the music in a variety of ways. There are a number of techniques, mechanisms, processes, and actions which take place, or are activated by composers, performers, listeners, and environments to bring about the experience of contingency in music. Contingency and chance can act on, or be acted on, by the composer or performer prior to the music-making event. This might be due to: the adoption of chance or process-based compositional procedures, deliberate "forgetfulness" in compositional and/or performance practice process (what Priest, 2013, 18 calls "intentional unintentionality,"; see also Feldman's composition process in Feldman and Friedman, 2000), or the collection or rehearsal of contingent music-making procedures (Bailey, 1993).

Additionally, contingency and chance can act on, or be acted on, in the music-making by a single performer or part or whole of the ensemble. This might be due to: deliberate or unintentional forgetfulness, long-form performance of persistent repetitions of limited musical material (that may be sounding in and out-of-phase with other performers' sound-making), deliberate destabilization of sonic continuities (Thomas and Payne, 2020), instrumental preparations or electronic sound-making processes, exploiting environmental resonances and psychoacoustic effects, and seeking to hide or reveal form and content by dynamic means (Hegarty, 2007; Beins et al., 2011). These elements or forces can also act on, or be acted on, by the audience or perceiver of the music-making – this might be due to: distraction or daydreaming, musical taste, deliberate listening choices, imagination, and physical impairment (Voegelin, 2014) – and by the environment of the music-making. This might be due to: the shape of the performance space, the presence or lack of sound reinforcement and amplification, the position of the listener in the space, the dynamics of the musical performance, the sonic content of the musical performance, and the placement of the performers (Conrad, 1997).

METHODOLOGY

The Experimental Composition Improvisation Continua

I contend that the historical definition of experimental music as "an act the outcome of which is unknown" remains a useful descriptor of music that deliberately engages with contingency and chance events, such as that which can exist in expressions of jazz, or expressions of field recordings, or prepared instrument practice, or any of today's innumerable contemporary stylistic outputs. Nyman outlines a continuum in experimentalism as follows:

> "The extent to which they [musical processes/acts/outcomes] are unknown (and to whom) is variable and depends on the specific process in question. Processes may range from a minimum of organization to a minimum of arbitrariness, proposing different relationships between chance and choice, presenting different kinds of options and obligations" (1999, 4).

I offer the *ECIC* as a model by which to investigate interactions in musical works between relative experimentalism on the one hand, and composition and improvisation on the other.[13]

[13]As previously discussed there have been studies which investigate a continuum between composition and improvisation, and those that investigate degrees of engagement with experimentalism; however, none so far that bring these continua together in a model.

The diagram in **Figure 1** shows what is essentially a field having two axes, the experimental axis and the composition-improvisation axis.

The composition-improvisation axis represents an infinite range of possibilities between the "ideal types" of the completely composed (i.e., premeditated, notated, or scored) and the completely improvised (i.e., in-the-moment, in-real-time, and performed). The experimental axis represents an infinite range of possibilities of musical activities from the "ideal types" of not experimental (i.e., having no engagement with contingency/chance/indeterminism) to completely experimental (i.e., completely engaged with contingency/chance/indeterminism).

The ECIC model makes it possible to consider, observe, track, or plot, musical activities and relationships. Any musical work can occupy any position on the continua field, at any time; and choices that are made or allowed, either physically or psychologically, will steer the work toward a particular mix of the three elements – composition, improvisation, more or less experimental – and a particular position on the ECIC field.

Composers and improvisers can and do adopt *various positions* along these continua, including at various times in their careers, and for a variety of reasons (for example, see Wolff, in Lucier, 2018, 12-30). Also within a single work, as mentioned, positioning may vary as it progresses. Similarly, the receivers of the musical work – the audience (or listeners, or perceivers) – may choose or occupy various perceptual positions within the span of one work, or adopt various listening positions across the years of their many and various musical engagements (Cook, 1990).

As a tool, the ECIC model must be employed relatively according to the user and context. Each person who employs it will bring their own set of assumptions and predispositions to the musical situation(s) being analyzed. The ECIC model provides a means to consider the various *qualitatively* apprehended engagements within and between experimentalism, composition, and improvisation, in musical works.

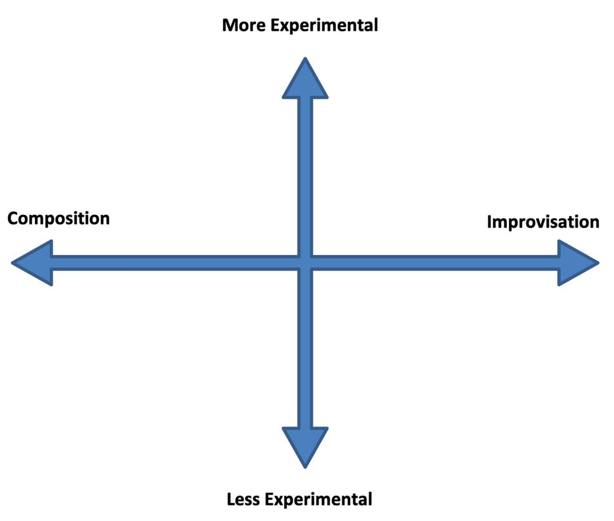

FIGURE 1 | The Experimental Composition Improvisation Continua (ECIC).

ECIC in Practice: An Analysis of Three Works

In the next section, three distinctive works are investigated using the ECIC as a tool in order to illuminate the presence or otherwise of various experimental interactions within them. The first work is "Spiral Staircase (SS)," a composition by written by Satoko Fujii in late 2007.[14] The second work is John Cage's *4′33″*, and the third is a 1965 performance of "My Favorite Things" by the John Coltrane Quartet.

RESULTS

"Spiral Staircase"

The recorded work referred to here is from an audio CD called *Heat Wave*, performed by "Ma-Do" quartet of Fujii (2008). The performers are Satoko Fujii (piano), Natsuki Tamura (trumpet), Norikatsu Koreyasu (double bass), and Akira Horikoshi (drum kit). I am using the term work, in this case, to refer to one specific performed and recorded iteration: an "event."[15] It is common practice in jazz and improvised music that, though one person may be afforded the composer credit for the work, it is understood the particular iteration is indebted to all performers as they are also compositional contributors, informing the final product. "SS," the work, is 4 min 25 s long and consists of a combination of composed and improvised sections. These sections are able to be detected aurally, *via* repetitions of complex material, pitch, and rhythm associations, and other changes in the sound as the performers interact. The composed material can be detected due to the presence of near-exact repetitions of passages of complex melodic and rhythmic material restated at various points throughout the work. ECIC interactions are evident from the beginning moments of this work. The first 34 s are occupied by the initial statement of the melody, with each performer playing a specific, pre-composed part on their instruments. However, from a perceptual point of view the nature and combination of the composed musical parts is stylistically, temporally, and formally ambiguous. The melody statement, played in unison on the trumpet and piano, sounds as a convoluted stream of eighth notes with an indecipherable metric structure that is interrupted at irregular intervals by low pitched sounds played with a loud dynamic in rhythmic unison on the piano, double bass, and drums, as shown in **Figure 2**.

This construction stimulate an indeterminate, contingent, listening environment, as the progress and outcome of the music neither cannot easily be traced or predicted, nor can a patterned relationship be determined between the music's parts. Stylistically, it sounds as if derived not only from jazz, but also, contemporary classical music, rock, and Okinawan court music (Spence, 2018). The ambiguity of form, content and, to some degree, style, encourages the listener to disengage expectation. If this section of the work were to be located on the ECIC field, a possible location would be toward the composition periphery of the composition/improvisation axis, due the sounding chiefly of pre-composed elements; and on the more experimental side of the more/less experimental axis, due to the perceptual indeterminism that the music engenders. In **Figure 3**, I have indicated this as a relative positioning marked with the letter "A" as it is the first ECIC event consideration in the timeline of the work.

The Piano Improvisation

The next section of the music that follows – here referred to as section B – contains the sounds of Fujii's improvisation on the piano and some sporadic accompaniment played at the beginning by Koreyasu and Horikoshi on the double bass and drum kit. It is 1 min and 40 s in duration and quite complex with respect to ECIC relationships. For a short period, the bass player and drummer play apparently pre-composed/notated rhythm and pitch interjections (notated by Fujii), in close-to-but-not-quite rhythmic unison. For the listener, it is very difficult to apprehend the logic behind the patterning of these interjections due to the temporal space between events and lack of audible metric pulse. Additionally, Fujii is playing quite different rhythms to those of Koreyasu and Horikoshi in her piano improvisation, and with an alternate, also ambiguous, metric association. These are shown in **Figure 4**.

The perceptual indeterminism of the accompaniment and its relationship to the pianist's improvisation is heightened by the seemingly indeterminate improvisational approach adopted by Fujii, who constantly changes rhythmic patterns and melodic material as her improvisation continues. The apparent arbitrariness of rhythm-pitch-melody relationships, the out-of-time asynchronous nature of the piano performance compared to that of the bass player and drummer, and the approximately timed, irregular iterations of the (composed) bass, and drum accompaniment, introduce elements of physical, performance indeterminism to the ECIC environment. For the performers, there is a sense of the unknown related to their performance; as to how, and when, and in what manner, it will interact with that of the other band members. Performance indeterminism combines to augment the already existing perceptually contingent listening environment. Point B2 (as indicated on **Figure 3**) shows a possible relative placement of this section of "SS" on the ECIC field: the indeterminate nature of the performance of composed elements combined with the improvisational focus of the music locates this point to the right of the center of the composition/improvisation axis. And the augmented contingent environment, due to physical as well as perceptual factors, accounts for this point being located further toward the more experimental periphery of the more/less experimental continuum than point "A." There are further musical developments in the piano improvisation section (B) that contribute to the perception of a change of position within the ECIC field. After 24 s from the beginning of this section, the bass player and drummer adopt an obvious, easily recognizable metric rhythmic accompaniment which lasts for 16 s. This doesnot seem to sway Fujii from her physically contingent course, however, it does steer the work perceptually more toward an equal distribution

[14] Fujii is an internationally recognized Japanese improvising pianist and composer, and a colleague with whom I have collaborated and performed since 2007. Regarding peer review see, for instance, Fujii's recorded work listed twice in the American jazz journal Downbeat (2020): The Year's Top-Rated Albums' (2020).

[15] Benson, while not disagreeing with the use of the word "work" for improvised realisations, also suggests the word "piece" as an alternative (2003, 132).

FIGURE 2 | "Spiral Staircase" melody excerpt (full score).

of composed and improvised elements. Point B2 (**Figure 3**) shows a possible location of this musical passage on the ECIC field. Following this, the bass player and drummer stop playing and Fujii's improvisation becomes more varied, as she incorporates a wider instrumental range; playing faster chromatic passages, and dividing the performance of the constantly changing rhythmic patterns between both hands, once again in a seemingly random fashion. This is an expressionistic, gestural approach such as that adopted by American free jazz pianist Taylor (1973), for example, on his piece "Indent: Second Layer" (analyzed in Westendorf, 1994, 125–155). These are gestures in which the shape of the improvisation is marked out in a general way by physical, "in-the-moment," un-premeditated actions. The resulting sound/pitch content of the improvisation is arbitrary and contingent on these actions. This third development within the B section of "SS" is marked as B3 on the ECIC field diagram. The perception of this last section of Fujii's improvisation is that the level of engagement with contingency and chance is increased due to bolder, arbitrary physical action, with no constraining or comparative structure (such as that provided earlier by the accompaniment of the bass player and drummer), and with highly contingent sonic results. At this point, the work is also perceived as having moved closer toward the improvisation periphery of the continuum. Following the piano improvisation, there is a re-statement of the melody played in a nearly identical fashion to the opening statement of the work. This is indicated on **Figure 3** as section C and is located on the ECIC field in the same place as point A for the same reasons as those listed earlier.

The Trumpet Improvisation

Tamura's trumpet improvisation follows (see **Figure 5**). This section of the music – called Section D in this analysis – is 52 s in duration. Like Fujii, Tamura appears to form arbitrary,

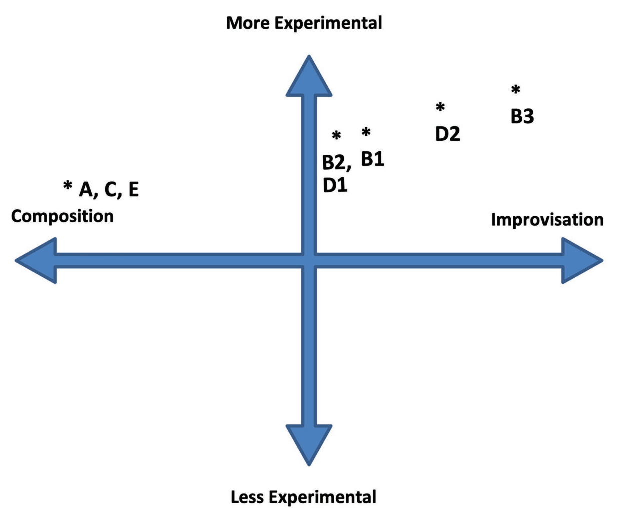

FIGURE 3 | ECIC interactions in "Spiral Staircase." The asterisk indicates the position of events: A, and/or B, and/or C, and /or B1, etc.

chromatic, and pitch relationships in his improvisation, though initially within a more restricted range. This time, the bass player and the drummer play a repeated rhythmic and melodic motif, with an easily discernible metric underpinning, that continues for the duration of the trumpet improvisation. This is indicated as point D1 on the ECIC field diagram at the same location as B2, and for similar reasons, due to the more or less equal distribution of composed and improvised musical elements combined with the physically and perceptually contingent nature of the trumpeter's improvisation. Once again, as with the pianist's improvisation, there is an apparent shift of position on the ECIC field as Tamura's improvisation progresses. This time, it is due to the entrance of Fujii, 20 s after the start of the trumpet improvisation, who plays dissonant, constantly changing chord patternings on the piano that are out of time with the bass and drums and unrelated harmonically to the sounds being made on the trumpet. This extra indeterminate element in the music shifts its position on the ECIC field as perceived by this listener. In **Figure 3**, it is shown as point D2. The work finishes as it started with a further statement of the composed "SS" theme. This section is shown on the ECIC field as point E, located once again in the same place as point A.

Summary of Factors in "Spiral Staircase" Affecting ECIC Positioning

Experimental Composition Improvisation Continua interactions are discernible in "Spiral Staircase" due to a range of factors. These factors include:

- Austerity and ambiguity of compositional style which require performers to interact in real-time to develop and extend the material.
- Irregular bass register interjections (in the melody sections of "SS," and in the piano improvisation), which deliberately disrupt narrative flow and destabilize apprehension of tonality, meter, and form.
- A performance approach that welcomes approximation or inaccuracy: as heard when the bass player and drummer are initially playing the accompaniment to the piano improvisation, or when Fujii deliberately ignores meter while accompanying Tamura's improvisation on the piano.
- Improvisational style which favors ambiguous rhythmic gesture, sudden change, juxtaposition, and welcomes indeterminism of pitch and time.
- Perceptual indeterminism due to ambiguous musical form and content, and the nature of the improvisation and contingent musical interplay between performers.

Performer Action vs. Listener Experience in *4′33″*

To demonstrate how the ECIC can be applied further, and to existing well-known works let's examine Cage's (possibly most famous) composition *4′33″* as performed by a solo pianist. This work is interesting from the point of view of investigating engagement with contingency and chance in a work, and the contrast between the experiences of the performer and the audience in its realization. *4′33″* relies on the audience and performer being together in the performance space. The piece is divided into three sections of varying lengths: 30 s; 2 min, 23 s; and 1 min 40 s, respectively. The actions generally employed by the pianist in this piece have evolved from those adopted in David Tudor's premier performance in 1952. They are as follows: to open the lid at the beginning of each section and close it at the end, before opening again for the next section (Holzaepfel, 2001, 2).[16] The performer needs to pay careful attention to a timekeeping device to ensure the sections of the piece are correct length. **Figure 6** shows with an asterisk a possible location of points A–D: where A is the point in the piece where the lid is lifted for the start of the first section, B is where the lid is closed then opened again for the second section, C is where the lid is closed then opened again for the third section, and D is where the lid is closed for the end of the third section and conclusion of the piece. The "P" in brackets indicates "performer." Because these actions are almost identical in terms of their relationship to composition, improvisation, and experimentalism, they are located with one asterisk toward the more composed and less experimental extremities of the ECIC model diagram. The nature of the audience's listening engagement in a performance of *4′33″* is central to the work. While the performer's role is essentially to enact concrete physical tasks (albeit without playing the piano keyboard), the audience's experience is dependent on their imagination. As this work is now well-known, most audience members will have some idea what to expect, however, when the lid of the piano is opened

[16]On the score, Cage has indicated that this piece can be played by any number of instrumentalists and for any length of time; however, the practice most adopted for solo piano follows that of the premier performance by David Tudor. It was Tudor, not Cage who "composed" the opening and closing of the piano lid for his performance of the premier of *4′33″* at the Maverick Concert Hall on August 29, 1952. This practice has remained as an integral part of the composition (Holzaepfel, 2001, 2).

FIGURE 4 | "Spiral Staircase" piano improvisation and accompaniment excerpt (full score).

for the first time and no sound on the instrument is made they need to determine what constitutes this piece for them. They can engage in this listening/realization process systematically, or creatively, or distractedly, or dismissively; but regardless of their approach they will be operating in the more experimental (contingent, chance dependent, and indeterminate), improvised (in-the-moment, in-real-time) quadrant of the ECIC model, as no sonic result that constitutes *4′33″* exists before they "compose" it in the moment (McAdams on perception as mentioned earlier). This is shown as a shaded area on the model in **Figure 6** to indicate the location of the myriad of possible perceptual choices or experiences in the realization of the work. The bracketed "A" letter indicates "audience."

The Sound of Effort and Experimentalism in the John Coltrane Quartet, 1965

On August 1, 1965, John Coltrane played a concert at a jazz festival in Comblain-la-Tour, Belgium with what was called his "classic" quartet: Coltrane (tenor and soprano saxophone), McCoy Tyner (piano), Jimmy Garrison (double bass), and Elvin Jones (drums). By this time, the band had been playing together constantly for 3 years, and Coltrane was becoming more

FIGURE 5 | "Spiral Staircase" trumpet improvisation and accompaniment excerpt (full score).

interested in free jazz. In early 1966, Coltrane recorded *Ascension*, a distinct move in this direction (see Jost, 1994). However, in 1965, the quartet's repertoire still included "show tunes" – popular tunes adapted to jazz. The quartet's performance of "My Favorite Things" at this concert offers a means to study ECIC relationships in this ensemble, particularly in connection with effort and gesture. Coltrane first recorded "My Favorite Things" on an album of the same name in 1961, and the quartet had played it regularly since then (Coltrane, 1961). The band's performance dynamic by this time was extremely energetic. As Ashley Kahn describes in the liner notes to the recording: "it was what the quartet delivered in extended doses: sustained, elevating energy and a marked density of musical ideas, a heightened sense of drama, and a sweat-inducing delivery that seemed to somehow articulate answers to spiritual mysteries. It was hip and hypnotic, frenetic, and at times frightening' (2007). As this quote indicates there was a sense in the ensemble, and among contemporary jazz music performers of the time, that playing at the limit of one's abilities was a means to discovery and the players worked hard musically to encourage each other in this quest. In musical terms, these passages of extreme effort cause or allow the most indeterminacy in this performance; either due to the individuals being close to their technical limits, taking risks and uncertain of the musical outcomes, or because of the combined sonic effect of the quartet's performance. This demonstration is the beginning of an investigation of ECIC relationships in Coltrane's soprano saxophone solo which is heard almost 131/2 min after the beginning of the work and continues for almost 3 1/2 min (**Figure 7**). The work is based on motoric repetitive rhythm

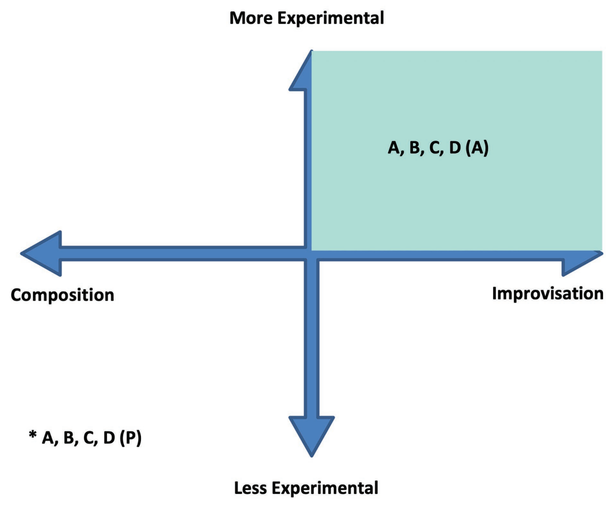

FIGURE 6 | *4′33″*: ECIC diagram showing performer and audience relationships. The asterisk indicates the performer's position on the ECIC at points (sections) A, B, C, and D, as referred to in the text.

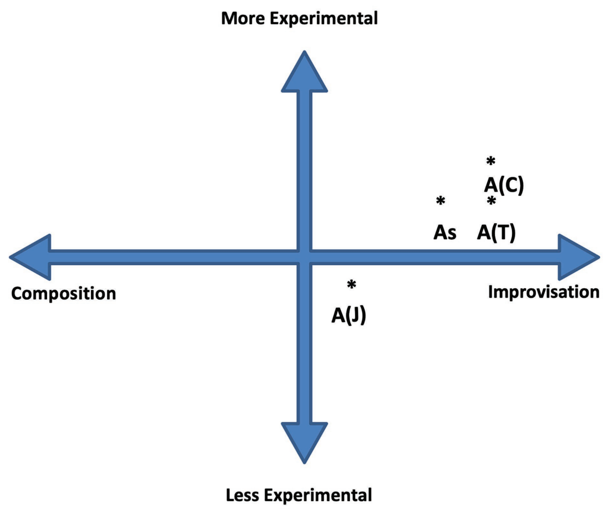

FIGURE 7 | ECIC relationships in Coltrane's solo on "My Favorite Things." The asterisk indicates the position on the ECIC of the individual performers in Section A of the performance of "My Favorite Things," as referred to in the text.

(over a 3/4 m) and at this point a repeated harmonic motif – one bar each of Emi7 chord then F#mi7 – underpins the whole saxophone solo. Tyner, Garrison, and Jones are performing as accompanists and have several roles: to maintain these underlying rhythmic and harmonic structures, to embellish and develop musical ideas from it, and to interact with the soloist and encourage them in their musical explorations. At time, the pianist and drummer are momentarily defaulting to pre-determined (composed) rhythmic and harmonic patterns that were played in the melody section of the work (and on performances previously). In this recording, the major changes in dynamics, interactivity, and musical texture are driven by Coltrane, Tyner, and Jones. Garrison's contribution, while not insignificant, has been excluded from this diagram. Four periods of group effort and gesture intensity have been identified in the almost 3 1/2 min saxophone solo. These are the points at which the music's relationship to experimentalism is most active. Each player has a slightly different or changing relationship with experimentalism (contingency/chance/indeterminism), composition, and improvisation, in these sections. For the purposes of this demonstration, I am only investigating what I have called section A, which begins 7 s after the beginning of Coltrane's saxophone solo. Section A occurs from 13′27″–13′39″ in the work. At this point Coltrane, who was playing short 16th note passages plays two 4-bar extended continuous chromatic 16th note passages, and Tyner modulates his chord voicing structures on the piano freely, in a seemingly random fashion, and in a vigorous contrapuntal manner, over a wider range of the instrument. Jones maintains the ongoing motoric rhythmic feel on the drums punctuated by one beat "fills" (embellishments) at the end of each bar. There is certainly musical tension here but there is also risk, uncertainty, contingency, heard in the occasional spectral splitting of the saxophone pitches, and the occasional indistinct chord played on the piano as the players struggle to maintain a coherent musical pathway. On the ECIC diagram, each player relationship with experimentalism, composition, and improvisation in this section is listed by the letter A followed by the initial of performer's surname in brackets. The overall perceived composite sonic result of the section is indicated by a lower case "s." The position of A on the diagram for Jones is more toward the composition end of the continuum but still within the improvisation half of the diagram, and less experimental due to less engagement with contingency and chance. Tyner and Coltrane are perceived as equally engaging with the more improvised end of the continuum, and Coltrane slightly more engaged with experimentalism due to the rapidity and chromaticism of the passages he is playing over the full register of the soprano saxophone. The overall sonic result is considered in this case as an approximation based on the various performances. The relationship with experimentalism is also affected by the short duration and regularity of this eight-bar exploratory section. As the solo progresses these sections become longer and the players more involved in interaction. Tyner and Jones take more risks in their performance and the sound of the ensemble begins to become one indeterminate entity, albeit within the restricted parameters of a motoric jazz performance in E minor. Section B is from 13′44″–14′08″; Section C from 14′09″–15′07″; and Section D 15′24″–16′08″. If musical relationships for these sections were to be plotted on the ECIC diagram, we could observe the changes in engagement with experimentalism, composition, and improvisation (This might be best illustrated with four separate ECIC diagrams to avoid overcrowding of information). Following this, the quartet settles into more regular rhythmic, harmonic, and melodic patterns, and Coltrane prepares to repeat the melody to "My Favorite Things."

CONCLUSION

There are a range of musical situations where the ECIC model might be applied. These situations involving composer, performer, perceiver, and environment can occur within the formation and realization of the work. As outlined ECIC considerations can be useful when determining the sources of contingency and indeterminism: whether this is due to the environment in which the work is performed, or due to the compositional or improvisational style, or performer action and interaction. However, ECIC considerations can also be of assistance when comparing musical works. These works can be similar or different in style and content (Spence, 2018). Applying the model helps to answer questions such as is contingency and chance the main focus of a musical work, or is it a by-product of the events that enable it (Spence, 2018)? Is indeterminism caused by physical action (human or otherwise) due to laws of physics, or is it psychologically activated; or a combination of both (psychoacoustic)? The ECIC model can also be of assistance when comparing a composer's stated aims or compositional approach or process, with the actual or perceived sounds of their work. For instance, indeterminism might be detectable, using the ECIC model, as being more or less at play in the composer's work than they are aware of, or that they indicate in published statements (Spence, 2018). Similarly, the composer's compositional technique can be examined through the lens of the ECIC. Do they employ chance techniques in order to complete a score (this can involve improvisational techniques as well as the use of externally imposed processes such as those made famous by Cage)? And to what extent is this perceivable in the sound of the compositional result? Do they consider the score as an end point, a blueprint for correct performance, or simply as a catalyst, or suggestion: a means to engage performers in the realization of a musical work? A performer's intentions and actions also can be investigated with reference to the ECIC model. For instance to what degree does their improvisational output demonstrate reliance on pre-learned ("pre-composed") motivic patterns, or in what ways do they deliberately, or by process, de-stabilize their performance environment in order to engage with contingent events as a driver for discovery and new ideas? How is their output affected by interactions with other performers, or the score, or the environment? This article has investigated the historical and ongoing relationship between experimental music, composition, and improvisation, and shown that while there are clearly identifiable interpenetrations between the practices, processes, and outcomes expressed in these musical approaches, there are nevertheless distinctions that characterize their ideal types. By identifying these distinctions and the continua between them, a model for experimental music investigation has been developed: the *ECIC* model. This model offers a way investigate and compare the action and operation of contingency, chance, and indeterminism, on composition and improvisation and the continuum between them. The application of the ECIC model to "Spiral Staircase," *4′33″*, and "My Favorite Things," demonstrates how one can more clearly appreciate the relationships between experimentalism, composition, and improvisation in these works, and from a variety of viewpoints, regardless of musical style. Considering a work from an ECIC perspective can help to identify points at which experimentalism, composition, and improvisation are more or less activated, and in comparison to other sections in the work; or compared to a composer's previous output; or compared to the "norms" of a musical style, or cultural approach. As indicated in the discussion of "My Favorite Things," multiple iterations of ECIC model diagrams can be applied to the one work. With longer works, different iterations can be dedicated to the various sections of the work. This can help to avoid overcrowding the ECIC field and for easier comparison between sections. Contingency and indeterminism are at play in almost all music, even when least thought to be active, such as in the performance of a "completely composed" music score. Here, also a continuum continues to be present between composition and improvisation (Bazzana, 1997). A case could be made for applying the ECIC model to all musical actions and outcomes. However, the ECIC has most relevance as an investigative and comparative tool in experimental music, where contingency is deliberately welcomed as a catalyst for new musical ideas and unknown outcomes. In this environment, as has been previously stated, the relationships between contingency/indeterminism/chance, composition, and improvisation are constantly in flux. In experimental, music, the ECIC model can be used to observe and investigate music composition, performance, and perception; across style, and scene, and culture; and the drivers for music, "the outcome of which is unknown," can be traced, isolated, and compared.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

REFERENCES

Alperson, P. (1984). On musical improvisation. *J. Aesthet. Art Critic.* 43:17. doi: 10.1111/1540_6245.jaac43.1.0017

Bailey, D. (1993). *Improvisation: its nature and practice in music*. New York: Da Capo Press.

Bazzana, K. (1997). *Glenn gould: The performer in the work: A study in performance practice*. Oxford: Oxford University Press.

Beins, B., Kesten, C., Nuack, G., and Neumann, A. (2011). *Echtzeitmusik Berlin: Selbstbestimmung einer Szene*. Germany: Wolke-Verlag.

Bell, C. (2005). The other side of silence. *The Wire* 260, 32–39.

Benson, B. E. (2003). *The improvisation of musical dialogue: A phenomenology of music*. Cambridge: Cambridge University Press.

Berliner, P. (1994). *Thinking in Jazz: The infinite art of improvisation*. Chicago: University of Chicago Press.

Borgo, D. (2002). Negotiating freedom: values and practices in contemporary improvised music. *Black Music Res. J.* 22, 165–188. doi: 10.2307/1519955

Cage, J. (2010). *Silence: Lectures and writings*. Middletown, CT: Wesleyan University Press.

Coltrane, J. (2007). John Coltrane Live in ‘60,‘61,‘65. USA: JazzIcons/Naxos. DVD Recording and liner notes.

Coltrane, J. (1961). My favorite things. Atlantic 1361. LP recording.

Conrad, T. (1997). Early minimalism volume one. USA: Table of Elements. CD Recording and liner notes.

Cook, N. (1990). *Music, imagination, and culture*. Oxford: Oxford University Press.

Cox, C., and Warner, D. (eds.) (2013). *Audio culture: Readings in modern music*. New York: Bloomsbury Academic.

Demers, J. T. (2010). *Listening through the noise: The aesthetics of experimental electronic music*. Oxford: Oxford University Press.

DiPiero, D. (2018). Improvisation as contingent encounter, or: the song of my toothbrush. *Crit. Stud. Improv.* 12, 1–17. doi: 10.21083/csieci.v12i2.4261

Downbeat (2020). The year's top-rated albums." Downbeat. Available at: https://downbeat.com/news/detail/2020-the-years-top-rated-albums/P3 (Accessed December 15, 2020).

Duckworth, W. (1995). *Talking music: conversations with john cage, philip glass, laurie anderson and five generations of american experimental composers*. New York: Schirmer Books.

Feldman, M., and Friedman, B. H. (2000). *Give my regards to eighth street: Collected writings of morton feldman*. Cambridge, MA: Exact Change.

Fujii, S. (2008). Heat Wave. Japan: Libra Records, 2008. CD Recording.

Goehr, L. (2007). *The imaginary museum of musical works: An essay in the philosophy of music*. Oxford, New York: Oxford University Press.

Gottschalk, J. (2016). *Experimental music since 1970*. New York: Bloomsbury Academic.

Gresser, C. (2007). Earle brown's ‘creative ambiguity' and ideas of co-creatorship in selected works. *Contemp. Music. Rev.* 26, 377–394. doi: 10.1080/07494460701414330

Hamilton, A. (2000). The art of improvisation and the aesthetics of imperfection. *Br. J. Aesthet.* 40, 168–185. doi: 10.1093/bjaesthetics/40.1.168

Hamilton, A. (2007). *Aesthetics and music*. London: Continuum.

Hamilton, A., and Pearson, L. (eds.) (2020). *The aesthetics of imperfection in music and the arts: Spontaneity, flaws and the unfinished*. London: Bloomsbury Academic.

Hegarty, P. (2007). *Noise/music: A history*. New York: Continuum.

Holzaepfel, J. (2001). “David Tudor, John Cage, and Comparative Indeterminacy." Getty Research Institute Symposium,“The Art of David Tudor.” Available at: https://www.getty.edu/research/exhibitions_events/events/david_tudor_symposium/pdf/holzaepfel.pdf (Accessed February 19, 2021).

Jost, E. (1994). *Free jazz*. New York: Da Capo Press.

Kim, R. Y. (2012). John cage in separate togetherness with jazz. *Contemp. Music. Rev.* 31, 63–89. doi: 10.1080/07494467.2012.712284

Landy, L. (1991). *What's the matter with todays experimental music?: Organized sound too rarely heard*. Chur, Switzerland; Philadelphia: Harwood Academic Publishers.

Lewis, G. E. (1996). Improvised music after 1950: afrological and eurological perspectives. *Black Music Res. J.* 16, 215–246. doi: 10.2307/779379

Lewis, G. E. (2009). *A power stronger than itself: The AACM and american experimental music*. Chicago: University of Chicago Press.

Lexer, S. (2010). Piano+: an approach towards a performance system used within free improvisation. *Leonardo Music J.* 20, 41–46. doi: 10.1162/LMJ_a_00011

Lucier, A. (2018). *Eight lectures on experimental music*. Middletown, CT: Wesleyan University Press.

McAdams, S. (1984). “The auditory image: A metaphor for musical and psychological research on auditory organization” in *Advances in psychology*. *Vol. 19*. eds. W. R. Crozier and A. J. Chapman (Amsterdam, The Netherlands: Elsevier Science & Technology), 289–323.

Nettl, B. (1974). Thoughts on improvisation: a comparative approach. *Music. Q.* 60, 1–19. doi: 10.2307/741663

Nettl, B., and Russell, M. (1998). *In the course of performance: Studies in the world of musical improvisation*. Chicago: University of Chicago Press.

Nyman, M. (1999). *Experimental music: Cage and beyond*. Cambridge: Cambridge University Press.

Peters, G. (2012). Certainty, contingency, and improvisation. *Crit. Stud. Improv.* 8, 1–8. doi: 10.21083/csieci.v8i2.2141

Piekut, B. (2014). *Tomorrow is the question: New directions in experimental music studies*. Ann Arbor: University of Michigan Press.

Piekut, B., and Lewis, G. E. (2016). *The Oxford handbook of critical improvisation studies*. *Vol. 2*. New York, NY: Oxford University Press.

Plourde, L. (2008). Disciplined listening in Tokyo: onkyō and non-intentional sounds. *Ethnomusicology* 52, 270–295. doi: 10.2307/20174589

Priest, E. (2013). *Boring formless nonsense: Experimental music and the aesthetics of failure*. New York: Bloomsbury.

Radano, R. M. (2009). *New musical figurations anthony braxton's cultural critique*. Chicago, IL: University of Chicago Press.

Reich, S., and Hillier, P. (2004) in *Writings on Music 1965–2000*. ed. P. Hillier (New York: Oxford University Press).

Rink, J. (1993). Schenker and improvisation. *J. Music Theory* 37, 1–54. doi: 10.2307/843943

Sarath, E. (1996). A new look at improvisation. *J. Music Theory* 40, 1–38. doi: 10.2307/843921

Saunders, J. (2009). *The Ashgate research companion to experimental music*. Farnham, UK: Ashgate.

Sawyer, R. K. (2000). Improvisation and the creative process: dewey, collingwood, and the aesthetics of spontaneity. *J. Aesthet. Art Critic.* 58, 149–161. doi: 10.1111/1540-6245.jaac58.2.0149

Schaeffer, P. (1966). *Traite des objets musicaux : Essai interdisciplines*. 2e Edn. Paris: Ed. du Seuil.

Schaeffer, P., North, C., and Dack, J. (2017). *Treatise on musical objects: An essay across disciplines*. *1st Edn*. Oakland, California: University of California Press.

Siepmann, D. (2010). A slight delay: agency and improvisation in the ambient sound world. *Perspect. New Music* 48, 173–199. doi: 10.2307/23076412

Small, C. (2011). *Musicking: The meanings of performing and listening*. Middletown: Wesleyan University Press.

Spence, A. (2018). “Accident and incident: experimental music practice and the contemporary composition improvisation continuum.” PhD thesis. University of New South Wales, 2018. Available at: http://unsworks.unsw.edu.au/fapi/datastream/unsworks:52499/SOURCE02?view=true (Accessed February 19, 2021).

Spence, A. (2020). “Championing risk and discovery: satoko fujii and the experimental composition improvisation continuum” in *The aesthetics of imperfection in music and the arts spontaneity, flaws and the unfinished*. eds. A. Hamilton and L. Pearson (London, Oxford, New York: Bloomsbury Academic), 253–269.

Stevenson, A. (2010). *Oxford Dictionary of English*. New York, NY: Oxford University Press.

Taylor, C. (1973). Indent. (USA: Arista. LP Recording)

Thomas, P., and Payne, E. (2020). “We also like to be surprised”: disruption, provocation and surprise in the music of Christian Wolff. *CircuiTree* 30, 27–45. doi: 10.7202/1071119ar

Toop, D. (2016). *Into the maelstrom: Improvisation and the dream of freedom*. New York: Bloomsbury Academic.

Voegelin, S. (2014). *Sonic possible worlds: Hearing the continuum of sound*. *1st Edn*. New York: Bloomsbury Academic.

Welsh, J. P. (1996). “Projection I (1950)” in *The music of Morton Feldman*. ed. T. D. L. (New York: Excelsior Music Publishing Company), 21–35.

Westendorf, L. (1994). “Analyzing Free Jazz.” DMA thesis. University of Washington. Available at: https://digital.lib.washington.edu/researchworks/handle/1773/11355?show=full (Accessed December 20, 2020).

Yaffé, J. (2007). An interview with composer earle brown. *Contemp. Music. Rev.* 26, 289–310. doi: 10.1080/07494460701414124

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Theories of Creativity in Music: Students' Theory Appraisal and Argumentation

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Most research on people's conceptions regarding creativity has concerned informal beliefs instead of more complex belief systems represented in scholarly theories of creativity. The relevance of general theories of creativity to the creative domain of music may also be unclear because of the mixed responses these theories have received from music researchers. The aim of the present study was to gain a better comparative understanding of theories of creativity as accounts of musical creativity by allowing students to assess them from a musical perspective. In the study, higher-education music students rated 10 well-known theories of creativity as accounts of four musical target activities—composition, improvisation, performance, and ideation—and argued for the "best theoretical perspectives" in written essays. The results showed that students' theory appraisals were significantly affected by the target activities, but also by the participants' prior musical experiences. Students' argumentative strategies also differed between theories, especially regarding justifications by personal experiences and values. Moreover, theories were most typically problematized when discussing improvisation. The students most often chose to defend the Four-Stage Model, Divergent Thinking, and Systems Theory, while theories emphasizing strategic choices or Darwinian selection mechanisms were rarely found appealing. Overall, students tended toward moderate theory eclecticism, and their theory appraisals were seen to be pragmatic and example-based, instead of aiming for such virtues as broad scope or consistency. The theories were often used as definitions for identifying some phenomena of interest rather than for making stronger explanatory claims about such phenomena. Students' theory appraisals point to some challenges for creativity research, especially regarding the problems of accounting for improvisation, and concerning the significance of theories that find no support in these musically well-informed adults' reasoning.

Keywords: argumentation, creativity, implicit theories, improvisation, lay theories, musical creativity, musical thought, theory choice

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INTRODUCTION

Theories and Informal Conceptions Regarding Creativity

General theories of creativity are based on the assumption that there is something we can call human creativity—that we can see creativity as one phenomenon, despite its apparent plurality. Definitions of creativity most typically share such characteristics as uniqueness (or novelty) and usefulness (see Plucker et al., 2004). While often sharing such basic assumptions, most contemporary theories of creativity are rather self-consciously demarcated to addressing only particular aspects of the multifarious phenomenon. This is easy to see in any of the introductory volumes and reviews available on the topic. Runco (2007), for instance, includes separate chapters on cognitive, developmental, biological, clinical, social, educational, historical, cultural, personality-based, and enhancement-oriented theories of creativity. In the present article, I will be referring to Kozbelt et al.'s (2010) review that similarly presents 10 (slightly different) classes of theories (see **Appendix 1**). Hence, while early theories of creativity might have appeared as unduly focused on cognitive aspects such as Divergent Thinking (Guilford, 1968) or "dissociation" (Koestler, 1964), the contemporary theoretical landscape is broader, addressing questions regarding creative lives, creative collaborations, creative products, the social and societal contexts of creative work, the neurological underpinnings of creativity, and more. It thus also seems clear that different creativity theories may address somewhat different sets of core questions (for a review, see Kaufman and Glăveanu, 2019). Some theories such as Csikszentmihalyi's (1997) Systems Theory take into account the reception of an idea or a product by a field of experts in a sociocultural context. However, many general theories of creativity tend to take a substantialist approach to creativity in the sense that the phenomenon (even in its societal aspects) is treated extrahistorically, as a human attribute, rather than as intertwined in historically contingent discourses and values (see Nelson, 2015, 2018).

Apart from developing scholarly theories of creativity, researchers have also paid attention to practitioners' conceptions and understandings of the phenomenon. This is understandable: any attempts to measure something as multifaceted as creativity could probably benefit from heeding the views of those with experience in the domain in question, in order to judge which aspects are relevant to consider. Artists, in particular, are typically taken as reliable informants about the nature and progress of their own creativity (e.g., Lindauer et al., 1997; Botella et al., 2013; Daniel, 2020), and artists' conceptions of creativity may indeed be richer than is the case for some other professions (Spiel and von Korff, 1998). By contrast, studies of teachers' conceptions of creativity have often emphasized the "informal," "implicit," or "everyday" character of their thinking, pointing out informants' misconceptions about the topic. In a review of empirical studies in this area, Mullet et al. (2016) find a difference between descriptors that K-12 teachers typically associate with creative individuals (imaginative, artistic, intellectual, etc.) and researchers' criteria for creativity (fluency, flexibility, etc.), concluding that, overall, "teachers' conceptions of creativity were limited, vague, or confused" (Mullet et al., 2016, p. 27). Whereas some researchers suggest that internal inconsistencies among teachers' beliefs might hinder their efforts to promote students' creativity (Kampylis et al., 2009), Mullet and colleagues go further, suggesting that the discrepancies between teachers' views and research "reflect teachers' difficulties in recognizing an authentically creative student or experience in the classroom" (Mullet et al., 2016, p. 24). In another review on K-12 teachers' conceptualizations of creativity, Andiliou and Murphy (2010) likewise pay attention to misconceptions, stating that the degree to which teachers' understandings of creativity align with researchers' views "becomes and essential issue with practical significance for teachers who wish to identify, develop, and evaluate creative outcomes" (Andiliou and Murphy, 2010, p. 203). These authors thus implicitly subscribe to what we might call *theory optimism* about creativity. This is the view that empirically supported theories of creativity give the best possible approximation about the central matters of fact regarding creativity and that creative phenomena can best be recognized and indeed furthered on the basis of this knowledge.

Influenced by Sternberg (1985), much of the research along these lines has been carried out using the term "implicit theory." In one of his experiments, Sternberg let laypersons rate how characteristic various behaviors would be for an ideally intelligent, creative, or wise individual. The top 40 behaviors in each case were then used in one of three sorting tasks in another experiment, where students sorted behaviors into piles reflecting which of them were "likely to be found together" in a person. For intelligence, creativity, and wisdom, the respective sorting tasks thus led to multidimensional scaling solutions concerning the dimensions of each of these constructs (ibid.). Such a scaling, of course, depicts the respondents' implicit theories on a group level, and it does not exclude the possibility that various participants' individual implicit theories might be mutually incompatible in some way. For the present purposes, it is interesting that the sorting task itself required the participants, in essence, to arrange the items in a *structure* that suggests a wider system of beliefs. Such a structural aspect warrants the use of the term "theory" in the sense that scientific theories, too, are structured entities (see Winther, 2015) and typically more complex than single beliefs. Guilford (1968, p. 22), for instance, saw theories as "semantic systems."

In the research concerning implicit conceptions about creativity, psychometric methods may have biased the results toward reporting particular beliefs instead of such larger structures of thought. For instance, many putative misconceptions about creativity—such as the belief that creativity is synonymous with the arts (e.g., Patston et al., 2018)—might be reported by rating a single questionnaire item. Similarly, methods using free association tend to yield lists of characteristics of creativity that may be condensed in categories signified by simple labels such as "beautiful," "curious," and "original" (Lothwesen, 2020). In more comprehensive factor-analytical (e.g., Cropley et al., 2019) or correspondence-analytical settings (e.g., Lothwesen, 2020), such beliefs do reveal a larger structure, but this is achieved by the researchers and describes the participants' thinking on a group level. Hence, these studies do not directly address participants' individual commitments to theories (in the sense of belief systems). In their analysis of studies concerning teachers' beliefs about creativity, Andiliou and Murphy (2010) rightly noted that uses of the term "implicit theory" (in Runco et al., 1993; Chan and Chan, 1999; Runco and Johnson, 2002) had been "narrowed and limited to represent beliefs [rather] than a belief system" (Andiliou and Murphy, 2010, p. 206).

In an attempt to transcend a psychometric approach that focuses on the quantification of isolated beliefs, Pavlović and Maksić (2019) studied university teachers' implicit theories of creativity using a qualitative questionnaire. They found five types of implicit theories and made more detailed observations of the contexts of applying the theories, arguing that the informants held individualistic attitudes regarding the general definition of creativity but moved to activity theories when they focused on manifestations of creativity in students. Likewise, several English interview studies with music teachers have suggested that teachers' views regarding creativity can be substantially shaped by their own teaching experiences (Crow, 2008; Odena and Welch, 2009, 2012; Kokotsaki, 2011, 2012). Such studies suggest that practitioners' views concerning creativity may be crucially influenced by the broader contexts in which they are embedded. In turning to examine conceptions of creativity in the domain of music, we should thus be reminded of the vast cultural differences that may exist in the practices and beliefs surrounding music. As Hill (2012) observes in an ethnomusicological setting, varying cultural beliefs about where music comes from may also fundamentally shape perceptions of what musical creativity is and who has the ability to be creative. Again, this underlines the importance of treating conceptions regarding creativity as parts of larger belief systems.

Theories of Creativity in Music Research

As one of the remarkably creative domains of human activity, music might seem to provide an interesting test case for general theories of creativity. Yet most research on musical creativity takes place in disciplines that are quite separated from general theories of creativity. This is well exemplified by the field of ethnomusicology—an area in which creative activities such as musical improvisation are recurrently studied. For example, none of the 36 chapters in Bruno Nettl's two important anthologies on musical improvisation (Nettl and Russell, 1998; Solis and Nettl, 2009) explicitly builds on any general theories of creativity, although some individual authors discuss such related areas as expertise research (see Pressing, 1998) and the psychology of "flow" (see Campbell, 2009; Turino, 2009), or briefly mention findings in the research on the development of creativity (Campbell, 2009). Rather than framing the phenomenon of musical improvisation by theories of creativity, the authors rely on the rich theoretical tradition of ethnomusicology itself, or find theoretical support from fields such as sociology, anthropology, linguistics, literary studies, semiotics, musicology, music theory, music education, or philosophy. Similar observations could be made in the recently expanding field of so-called critical improvisation studies that covers but is not limited to addressing musical improvisation. Among the 56 main chapters of *The Oxford Handbook of Critical Improvisation Studies* (Lewis and Piekut, 2016), Dean and Bailes (2016) briefly compare Pressing's (1988) theory of improvisation to the Geneplore model of creativity (Finke et al., 1992) while Young and Blackwell (2016) mention Boden's (1990) notion of transformational creativity. Otherwise, only a handful of authors refer to Csikszentmihalyi's "flow," give references to creativity studies in footnotes, or mention scholars such as Amabile or Simonton, but without referring to their main theoretical contributions in the study of creativity (as reflected in, say, Kozbelt et al., 2010). Such examples might raise some concern: are general theories of creativity perhaps unknown to improvisation scholars or deemed inappropriate or irrelevant by them?

The disregard for general theories of creativity by researchers of particular forms of musical creativity may seem surprising, but it often has good disciplinary reasons. Culturally oriented scholars, for instance, may see some general theories of creativity as too cognitive in their focus or as inappropriately relying on modernist ideologies of individual "innovation." Thus, drawing on creativity research in fields such as ethnomusicology or media studies might tend to be delimited to theories with a social bent—such as Csikszentmihalyi's (1997) Systems Theory (McIntyre, 2006, 2008; see, e.g., Borgo, 2007) or Sawyer's (2003) work on group creativity (e.g., Borgo, 2007; Schuiling, 2019). Another related aspect is that many culturally oriented music scholars may feel that they are "fighting the good fight against universalizing theories and culture-blind scholarship" (Slominski, 2020, p. 227). An epistemological commitment like this can be hard to square with the apparent generality of creativity theories. Moreover, such disciplinary self-understandings can also be intertwined with writing styles. For instance, some researchers in musicology like to begin their studies *in medias res*, avoiding generalizing theoretical frameworks—something that is amply demonstrated by many of the introductory sections to articles in the abovementioned volumes by Nettl.

But similar sentiments are common in other disciplinary fields, as well, such as in the psychology of music and related empirical disciplines. This is no place for a comprehensive review of the field in which researchers such as Sawyer (2003), Johnson-Laird (2002), and many others have made important contributions to creativity research. What I want to point out is the uneasiness which other prominent researchers have expressed regarding general theories of creativity. In their introduction to the first modern anthology on musical creativity in this area, Deliège and Richelle urged us to "get rid of *creativity*, and look at *creative acts*" (Deliège and Richelle, 2006, p. 2; emphasis in the original). In another relevant anthology, editors Hargreaves et al. (2012) similarly argue against general theories of creativity, writing: "Since creativity actually exists in so many different forms, activities, and contexts, giving rise to an infinitely variable range of products, any attempt to formulate a unitary description or explanation is doomed to failure" (Hargreaves et al., 2012, p. 4). Interestingly, Hargreaves and colleagues also suggest that "a focus on imagination—on internal mental processes—is more useful than one on creativity because it encompasses a much broader range of concepts and behavior" (Hargreaves et al., 2012, p. 3). In this view, then, creativity as a topic seems too limiting (apparently leaving out forms of imagination such as listening that do not involve some kind of product) but at the same time too general to be addressed in unitary theories.

Various strands of scholarly particularism may nevertheless differ between one another in terms of what to do with the concept of creativity. As seen above, some scholars are suspicious of the whole concept, which easily leads to *theory skepticism* regarding any general theories of creativity—often expressed without detailed scrutiny of such theories. As an extreme position, Frith, in discussing power relations in particular domains of record production, extends this skepticism to the domain-specific notion of "musical creativity." According to his view, this notion "is more of a hindrance than a help in understanding music-making practice," and thus "we should cease to use the term altogether" (Frith, 2012, p. 71). Other particularists have taken more positive views, trying to save the notion of creativity by insisting on its inherent plurality. Burnard's (2012a) bottom-up sociological accounts of various "musical creativities" provide a case in point. Such views also open the door to questions regarding how some theories of creativity might have something meaningful to say about music. Indeed, asking such questions on a level closer to the phenomena of interest reflects a non-universalizing tendency among general creativity researchers, as well. In the preface to his introduction to theories of creativity, Runco (2007, p. x) suggests that "the creative process is multifaceted" and complex to the extent that an "eclectic approach is necessary." According to such *theory eclecticism*, the suitability and usefulness of particular theories would always have to be contextually determined. Hence, even if creativity is conceptualized as a unitary phenomenon or as a "distinct and independent capacity" (Runco, 2007), this complex totality would still need various theoretical tools to be properly accounted for. Finally, still another position—we might call it *theory revisionism*—arises out of the concern that mainstream approaches to theorizing about creativity have simply been too individualistic, too mentalistic, or too product-oriented and that the whole field could be reoriented on this level. Most notably, perhaps, there has been growing interest in distributed, ecological, or 4E approaches to creative cognition in music (Linson and Clarke, 2017; van der Schyff et al., 2018; Schiavio et al., 2020). In the work of Clarke and his associates, for example, the distributed nature of musical creativity has been demonstrated through detailed case studies of micro-social interaction and embodied instrumental engagement (Clarke et al., 2013, 2017).

In some areas of music research, a certain theoretical eclecticism regarding general theories of creativity appears to emerge from the larger research field, although rarely as an explicit position of individual researchers. A systematic review of this topic would require a separate undertaking, but some instructive examples can be provided, say, in Collins (2012) anthology on creative processes in musical composition. Of the 11 chapters in the volume, seven explicitly reference one or more general theories of creativity. Some authors address composition as an individual creative process: Katz (2012), for instance, takes her lead from such theories as Galenson's typological scheme of "experimental innovators" and "conceptual innovators" (or "seekers" and "finders"; see Galenson, 2001, 2006, 2009), and Wallas's (1926) Four-Stage Model of creativity—suggesting that creative processes involve successive stages of preparation, incubation, illumination, and verification [Wallas (1926, p. 97 ff.) also paid attention to an "intimation" stage when illumination was imminent]. Wiggins (2012), in turn, theorizes composition relying on Boden's (1990; 2010) ideas of creativity as the exploration or transformation of conceptual spaces. Brown and Dillon (2012) discuss modes of meaningful engagement with musical composition, drawing on de Bono's (1992) thoughts of creativity as finding alternative perceptions or conceptualizations and on Dennett's (2001) pseudo-Darwinian emphasis of exploitation of accidents. Bailes and Bishop (2012) address various forms of compositional imagery, seeing them to align with Ainsworth-Land's (1982) general stage development model of creativity. Among the more socially informed views, Burnard's (2012b) presentation of real-world composition practices is guided by Amabile's (1996) views regarding the social dimensions of creativity, and Bennett's (2012) analysis of collaborative songwriting is influenced by the Systems Theory of creativity. Other authors rely more on theoretical approaches indigenous to the field of music and/or develop their own theoretical models for musical composition.

Even this small collection of examples suggests that the field of creativity research can easily be sampled for support to a wide range of perspectives into a more or less circumscribed form of musical creativity (here, composition)—without much concern for how other, competing theoretical schemes might have handled the task. In Collins' volume, one finds very little explicit argumentation regarding theory choice: many of the authors write as if they would have already made up their minds about which theoretical framework to stand upon. The clearest exception in the anthology appears in Kozbelt's (2012) account of composers' lifespan creativity trajectories. Kozbelt first pits the expertise acquisition view of creativity (Ericsson, 1999) against the Blind Variation and Selective Retention view that emphasizes serendipity in the creative process (Campbell, 1960; Simonton, 1997, 1999, 2010, 2015), noting that these two theories "make radically different assumptions about the fundamental nature of creativity and quite divergent predictions about how creativity unfolds throughout creators' lives" (Kozbelt, 2012, p. 28). Subsequently, Kozbelt argues that results concerning composers' career landmarks are hard to reconcile with the two abovementioned theories but are better accounted for by using Galenson's typological approach. Pending a systematic review of other similar literature in the field, I venture the suggestion that such comparative argumentation about the relative empirical adequacy of creativity theories is rare within music research. Finally, a complementary question that is typically left open in contexts such as the abovementioned anthology is how the chosen theories would fare in the case of other kinds of creative musical activities. The theoretical eclecticism regarding theories of creativity that arises from the combined efforts of music researchers thus tends to leave both theory choice and the scope of the theories inexplicit.

Rationale for the Present Study

The importance of studying creativity is often taken for granted by researchers (see Forgeard and Kaufman, 2015), but in the case of music this may be less of a problem than in some other fields. Few might question the idea that music is a creative field of human activity. As the above review suggests, however, the relevance of *theories* of creativity for music is less clear. While the position of theory optimism would imply that general, empirically grounded theories of creativity might be used to correct musical practitioners' views and even enhance their creative potential, theory skepticism would claim the primacy of the actual practices, treating any attempts at theoretical systematization with suspicion. In my view, both of these positions are problematic as applied to music. Theory optimism appears complacent: instead of assuming that music specialists' conceptions can offer valuable insights into creativity (see e.g., Koutsoupidou, 2008), it assumes that researchers should start correcting creative practitioners in their views. Moreover, theory optimism might even seem to suggest that creative practices are best furthered by *convergent*, theoretically systematic thinking about creativity—rubbing against the notion of creativity as divergent thinking. Theory skepticism, in turn, would seem to jump to conclusions: against the fact that at least some musical creators and researchers have found use for general theories of creativity, it simply dismisses such examples without empirical scrutiny.

While it may be granted that much informal thinking on creativity can be reflected in simple questionnaire items, the present research was based on the assumption that people might equally well be able to relate to more complex, scholarly theories regarding the topic. Given that the gist of many theories of creativity is expressible in rather non-technical terms (see **Appendix 1**) and that many of them have been inspired by creative individuals' own reports, we could indeed expect such theories to be understandable to at least educated practitioners in a field such as music. This is also suggested by how creativity theorists often become sought-after speakers outside of the academia. In such contexts, scholars may tend to promulgate their own theoretical views rather than seeking to subject them to comparative scrutiny. At least to my knowledge, there have not been systematic efforts to ask ordinary people or practitioners in a field about their reactions to broader selections of creativity theories. Therefore, we might not even know whether some such theories would tend to be rejected outright by the relevant practitioners themselves. The current study was thus based on curiosity: assuming that musical practitioners' activities are supposed to be covered by general theories of creativity, what would such practitioners themselves say about these accounts? Of course, we cannot expect theories in behavioral sciences to be automatically felled by lack of acceptance by those whose actions are accounted for. Still, some more knowledge about creative people's appraisal of theories concerning their domain would certainly help us untangle some of the knots in the mixed reception that these theories have generated.

In designing the study, I thus tentatively adopted the position of theory eclecticism—not as a given result, but as methodological guidance. The aim was to study the appraisal of theories of creativity among higher-education music students, by building on the assumption that theories might vary in their suitability in accounting for different musical activities. In allowing the participants to engage with theories of creativity, I also wanted to embrace the positive suggestion inherent in theory optimism—that practitioners could be offered information about creativity research. Finally, in asking the participants to evaluate the suitability of such theories for music, I opened the door to such views as theory skepticism, theory eclecticism, and even theory revisionism as possible result scenarios.

In an empirical study of people's theory appraisals, it seemed wise to adopt the Kuhnian assumption regarding indeterminacy of theory choice. Kuhn (1977) acknowledged that choice between theories in science depends on such traditionally recognized criteria as accuracy, consistency, scope, simplicity, and fruitfulness. However, he also claimed that theory choice is indeterminate both because the criteria themselves may be imprecise and because individuals may weigh such values differently to resolve possible conflicts between them. If theory choice in science thus involves "idiosyncratic factors dependent on individual biography and personality" (Kuhn, 1977, p. 329), this could be expected to be even truer for students' appraisals of theories, not least in a "softer" field such as creativity studies.

In the present study, I chose to work with higher-education students majoring in musicology and music education. Students of musicology are rarely engaged as participants in studies of creativity, but here they were chosen in order to cover a wider range of active musical interests and creative attitudes, also potentially differing from those of pre-service music teachers. While such individual differences might affect the appraisal of theories, it also seemed relevant to ask whether the theories might indeed be differently evaluated in different musical contexts. Based on the review above, I assumed that some theories might encounter problems at least when applied to musical improvisation. Hence, the first research question was about the judged scope of the theories and about systematic biases in theory appraisal:

RQ1: Is the appraisal of theories of creativity in a musical context affected by (a) differences between musical target activities and/or (b) the characteristics of the individuals making the judgments?

While this question will first be addressed on the basis of quantitative ratings, such results can hardly suffice to demonstrate the complex ways in which individuals might come to favor certain theories over others. A low rating, say, does not contain information about the reasons for giving a low rating: for one of the participants, the reason might be a sense of lacking conceptual clarity; for another, it might be unsuitability to account for subjectively meaningful experiences, and so on. In order to understand the students' thinking on this level, we may study their argumentation. I thus chose to let music students write essays in which they would argue for their choice of creativity theories in a musical setting. In broad terms, arguments can be thought to be composed of claims and justifications for those claims. For instance, in Toulmin's (1958) scheme, claims are justified by "data" (i.e., facts) and "warrants" that register the legitimacy of appealing to the kinds of data in question, as well as "backing" for the warrants. The structures of student-generated arguments, too, are typically understood to consist of a claim-like component and one or more justification components, the types of which differ between analytical frameworks (see Sampson and Clark, 2008). In the present case, claims concern the suitability of a given theory to musical creativity in general or to a particular kind of musical activity. Justifications, in turn, might conceivably differ between individuals. For instance, some students might refer to their personal experiences as support while others could rely on more abstract reasoning. In the present context, I will forgo trying to explain such individual preferences in argumentative style. Assuming a range of justificatory strategies, the second research question addressed instead the possibility that these strategies might be context dependent:

RQ2: In applying theories of creativity to music, are students' argumentative strategies dependent on the theories in question and/or on the musical target activities?

Studying music students' theory appraisal should help toward a better understanding of the relationships between theories of creativity and musical practitioners' views. My working assumption was that musically active adults are not only able to channel many of their implicit conceptions through the conscious application of scholarly theories but that they could also offer potentially valuable criticism regarding such theories. Being embraced by higher-education music students might not, of course, be necessary for a good theory of musical creativity, but a potential lack of such acceptance should at least raise interesting questions about the nature of the theories. The third research question thus addressed the fate of the theories in students' hands:

RQ3: Which theories of creativity do the students find particularly suitable for musical activities, and which ones do they find problematic in this respect?

Notice that a relative theory skepticism or a theory eclecticism on the part of the students could be potential answers to this question. However, eclectic choice of theories, in particular, would also raise new questions about the supposed nature of theories and how they are to be used and chosen. Thus, the final research question was an overarching one:

RQ4: What are students' dominant conceptions of theories and theory choice?

METHODS

Research Strategy

The overall research strategy was based on the idea that different aspects of students' theory appraisal could be captured by different methodological approaches. First, the influence of target activities and individual characteristics on theory appraisal (RQ1) was addressed in a quantitative approach, working with theory ratings. Second, the dependence of argumentative strategies on theories and target activities (RQ2) was approached in a mixed-method approach in the sense that qualitative and quantitative aspects of the analysis were integrated before drawing conclusions (see Bazeley, 2018). Third, students' views regarding the suitability of the particular theories (RQ3) were addressed in a multimethod approach in which both quantitative and qualitative results provided complementary results that could be integrated while drawing conclusions (Bazeley, 2018). Finally, the question about students' dominant conceptions regarding theory choice (RQ4) could only be addressed by way of a philosophically oriented interpretation of the whole set of empirical results. Thus, the final research question will be postponed to the discussion.

Participants

The participants were 47 Finnish university students of music, with a mean age of 27.4 years (sd = 6.8). They were majoring in either musicology (18 females, 16 males) or music education (8 females, 5 males). They took part in the study while taking an advanced course in musical creativity, either in 2013 (22 participants) or in 2015 (25 participants). Thirty-five of the students were at least in their fourth year of university studies, and 18 of them had a previous conservatory degree. The participants reported an average of 15.3 years of active musical experience (playing or singing; sd = 7.6), and they reported to play 3.2 different musical instruments, on average (sd = 2.0). On a scale between 0 ("not at all experience") and 5 ("very much experience"), their reported average experience in composing (M = 3.2, sd = 1.3), improvisation (M = 3.0, sd = 1.3), working with music technology (M = 3.0, sd = 1.2), and teaching music (M = 2.6, sd = 1.7) were all above the midpoint of the scale. They did not have much experience in instrument making (M = 0.5, sd = 0.6). In assessing their own experience of making music in various genres on similar scales between 0 and 5, they reported most extensive experience in the areas of popular music (M = 3.7, sd = 1.2) and Western classical music (M = 3.2, sd = 1.7), while most had less experience from jazz (M = 1.9, sd = 1.2) and folk music (M = 1.8, sd = 1.4).

Material

In order to avoid personal biases in the choice of theories, I selected the chapter "Theories of Creativity" (Kozbelt et al., 2010) from the first edition of the *Cambridge Handbook of Creativity* as the basis of the study. The chapter offers a balanced review of general (non-domain-specific) theories of creativity, emphasizing theoretical pluralism. The first main section of the chapter discusses classifying and comparing theories, categories of creative magnitude (e.g., "Big C/little c" creativity), the so-called four Ps of creativity (process, product, person, and place), and related schemes. The second main section includes 10 subsections, introducing the reader to as many categories of more specific theories presented in the research literature.

From each of these 10 subsections, I selected one theory that appeared to be most thoroughly described. As an exception, two theories were selected in the section "Stage and componential process theories" (reflecting both of these two aspects), and the theory of Divergent Thinking got to represent two of the subsections in which it figured centrally. For each of the chosen 10 theories, I extracted what I interpreted as core descriptive sentences regarding the basic content of the theory, removed references to literature, and substituted theorists' names with general descriptions (e.g., "some theorists"). If required, sentences from different parts of the original text were patched together, adding some words where needed. In each case, the goal was to achieve a brief, coherent description, keeping as close as possible to the handbook text. The descriptions are shown in **Appendix 1**, complete with quotation marks to indicate the original passages. Square brackets indicate words or phrases added to the original wordings for clarity, or places where references or other words have been removed from the citations. For presentation in the study, the quotation marks and square brackets were removed, arriving at 10 concise theoretical summaries. These ranged from 2 through 6 sentences, depending on how much material was available in the handbook text.

Procedure

In two separate years, two groups of music students took part in a course on musical creativity. In the beginning of the course, they were given the assignment to read the original handbook chapter by Kozbelt et al. (2010), after which they took part in one of two 1-h sessions in which the chapter's contents were discussed. In facilitating the group discussions, I strived to refrain from all value judgments regarding the theories and avoided providing explanations beyond what was said in the handbook chapter. Instead, I attempted to ensure that all 10 theories were discussed, encouraging the participants to apply the theoretical ideas to their own musical experiences. The students were oblivious to the later assignment in which the theoretical summaries would be used.

During the following 3 months, the students took part in 10 classes focusing on various aspects of musical creativity on the basis of readings from different areas of music research. The obligatory readings covered topics in music history, including the myth of genius (Higgins, 2004), originality and plagiarism (Buelow, 1990; Winemiller, 1997), and theories of musical influence (Straus, 1990; Yudkin, 1992); readings in improvisation from ethnomusicological (Nettl, 1974; Nettl and Riddle, 1998), pedagogical (Tafuri, 2006; Huovinen et al., 2011), and cultural perspectives (Lewis, 1996; Prévost, 2004); issues of musical creativity and mental health (Nettle, 2001); social aspects of musical creativity (Frith, 2012; Littleton and Mercer, 2012); empirical research on creativity in musical performance (Williamon et al., 2006; Clarke, 2012); and philosophical aspects of the creative experience (Huovinen, 2011). Chapters from the textbook on creativity research by Runco (2007) were recommended for optional readings throughout the course, but general theories of creativity were not in focus during the class discussions during this period. The course also introduced the notion of conceptual ideation through a practical exercise in which the students created and wrote up "ideas for making music in a new way." Students' written ideas—ranging from plans for new instruments through compositional algorithms to ideas for social organizations of musical life—were shared with and evaluated by other participants in the group.

Twelve weeks after their group discussion on Kozbelt et al. (2010), the students participated in one of two 105-min class sessions in which they received a questionnaire incorporating the 10 theoretical summaries edited from the handbook chapter. The students were instructed to carry out three tasks. First, they were asked to read the theoretical summaries and to evaluate the theories on 6-point Likert scales for suitability in accounting for (a) musical improvisation, (b) musical composition, (c) performance of composed music, and (d) creating ideas for making music (henceforth: "ideation"). It was explained that they should assess to what extent each of these areas of creativity would be describable, researchable, and/or understandable through the given theories. The four target activities were not further defined; instead, it was hoped that the students' varying musical backgrounds and experiences would be reflected in a wide range of understandings concerning such activities.

Second, the students were asked to choose 1–4 "best theoretical perspectives" that "best correspond to your own thoughts about what is central for musical creativity." Their task was to write an essay justifying their choice of theories, paying attention to whether various forms of musical creativity might require different theoretical perspectives. The students were also encouraged to reflect on possibilities for research in connection with the theories, to discuss problems in applying the theories to music, and to suggest refinements to the theories for the purpose of using them in musical contexts. No instructions were given concerning the lengths of the essays.

In order to assess the possible effects of personality on theory choice, the Five-Factor Model of personality (Digman, 1990), also known as the "Big Five" (Goldberg, 1993) was assumed as a starting point. The students filled out background questionnaires as well as the "Short Five" personality test (Konstabel et al., 2012), measuring the 30 facets of the Five-Factor Model with 60 comprehensive single items (positive and negative statements intended to match expert descriptions of the constructs). The Finnish-language version of the test used here has been shown by Konstabel et al. (2012) to have good to excellent congruence with the structure of the standard NEO Personality Inventory-Revised (see Costa and McCrae, 2014).

All students received course credit for the assignment. It was explained that apart from the course assignment, they could freely choose to allow their responses to be used anonymously in the author's research, and that in so doing, they could withdraw from the study at any time. Six students did not agree to participate, and their responses were removed from the data reported here. The remaining 47 participants gave their informed consent in written form. The background information reported above as well as the results concern these 47 participants. Institutional guidelines for ethical practice were followed throughout the study.

Analysis

Quantitative analyses of the ratings were carried out in the *R* environment for statistical computing (R Core Team, 2019), using the package "psych" for principal component analysis of theory ratings (Revelle, 2019). Linear mixed-effect models for the ensuing principal components were built using the "lme4" package (Bates et al., 2015), and estimated marginal means were produced using the "emmeans" package (Lenth et al., 2019). Other quantitative methods involved in the analysis of ratings were Kruskal–Wallis and Mann–Whitney U-tests, as well as the Pearson correlation coefficient.

The participants wrote their essays in Finnish, apart from two bilingual participants who chose to write in English. The hand-written essays were first typed into digital format. Their length ranged between 1,752 and 8,892 characters (spaces excluded), with a mean of 3,672 characters ($SD = 1,571$) per essay.

A content analysis of the essays was carried out by coding them in the program NVivo (QSR International Pty Ltd, 2018). This involved three separate content codings, initially marking passages for (1) each of the 10 theories of creativity and (2) each of the four target activities mentioned in the task instructions (improvisation, composition, performance, ideation). In both of these cases, coded passages could range from parts of sentences up to longer paragraphs (and in rare cases, even the entire essay, when the same construct had been given a longer, continuous discussion), and several overlapping codes could be used. Finally, the text was coded for (3) argumentative content, based on the idea that arguments consist of claims and justifications (e.g., Sampson and Clark, 2008). Claims, in this case, were assertions concerning the suitability of a given theory to account for musical creativity (or some form thereof). Quantitative aspects of the essay responses were analyzed in *R* using χ^2 tests for the equality of proportions and hierarchical cluster analysis (using the complete linkage method).

RESULTS I: RATINGS

Theory Ratings and Theoretical Dimensions

The highest mean rating was obtained by Amabile's (1996) Componential Theory (M = 3.9, sd = 1.1), closely followed by Divergent Thinking (M = 3.6, sd = 1.3) and Systems Theory (M = 3.5, sd = 1.3). However, for eight of the theories, Kruskal–Wallis tests with *p*-values adjusted for multiple comparisons showed significant ($p < 0.01/10$) differences in ratings between the four target activities. These differences are shown in **Figure 1**, using compact letter displays to indicate pairwise comparisons between activities (Dunn's tests). Generally, differences between target activities were smallest for theoretical summaries making no claims about the creative process (Developmental View, Systems Theory, Componential Theory), whereas some other theories were deemed relatively unsuitable either for musical improvisation or performance (or both). In particular, the Four-Stage Model and the Investment Theory (Sternberg and Lubart, 1991; Sternberg, 2012) seemed least acceptable as accounts of musical improvisation.

Each theory was rated by the participants four times, relating it to each of the four musical target activities; thus, for each theory there were 188 ratings. It would be unlikely that all such sets of ratings would be completely independent of one another. Instead, we could expect to find a smaller number of basic theoretical dimensions along which several theories receive similar ratings in a number of musical contexts. In order to condense the rating data to such dimensions, a principal component analysis (with varimax rotation) was carried out, extracting four components (with eigenvalues larger than 1). The resulting analysis is seen in **Table 1**, showing loadings above 0.4.

I have tentatively named the four emerging theoretical dimensions according to salient common ideas shared by the theories with high loadings on these dimensions. The first component could be interpreted as focusing on an *Orderly Process*: the two theories with highest loadings on this component (Problem-Solving and Four-Stage Model) emphasize an orderly thought process through which an idea or solution is reached. The inclusion of Seekers/Finders in this component may reflect the fact that both types of creators were accounted for by their characteristic working processes. In other words, it is the emphasis on process rather than either of the types of creators that groups this theory with the two others. The second component, *Strategic Divergence*, appears to center on making a strategic contribution by investing in a new idea (Investment Theory) or a new problem (Problem Finding) that diverges from commonplace solutions in its originality (Divergent Thinking). Notice that all of these three theories require the creative achievement to be assessed in its historical dimension (as "H-creativity"; Boden, 1990) or in terms of some other comparison to standard achievements. The third component also involves Divergent Thinking, but this component could be called *Darwinian Divergence*, as it is dominated by ideas of Blind Variation/Selective Retention and development through environmental influences (Developmental View). Finally, the fourth component highlights creativity as a *Socio-Cognitive System*: it includes theories that describe creativity as involving a field of gatekeepers (Systems Theory) or as an interaction between dispositional, cognitive, and social aspects (Componential Theory).

Target Activities and Individual Characteristics

Equipped with a more condensed account of the theoretical dimensions, we may reformulate the first research question and ask: does the appreciation of the four theoretical dimensions depend on types of musical activities considered and/or on the evaluator's own individual characteristics or musical background? To address this question, the principal component scores were normalized between 0 and 1, yielding four synthetic variables, one for each theoretical dimension.

None of these variables appeared to be significantly affected by participants' gender or the participants' major subject of study (Mann–Whitney *U*: all $ps > 0.1$). To study the possible effects of other background variables, I constructed linear mixed-effect models for each of the principal component scores, taking participant as random effect. In each model, musical activity was included as a fixed effect. To choose other fixed effects, Pearson correlation was first used to screen the participants' background variables for associations with the theoretical dimensions (for the linear modeling, these variables were interpreted as interval variables). Apart from participants' age, year of study, years of musical activity, and the five facets of the Short Five personality test (N, E, O, A, C), the variables considered included self-evaluations (on a 6-point scale) regarding experience in composition using traditional notation, composition with other means, improvisation, music technology, and music teaching, as well as playing music in the areas of classical music, popular music, jazz, and folk music. The preliminary correlation analysis revealed only very few potentially relevant background variables, most notably composition experience (using traditional notation) and jazz experience.

Using a likelihood-ratio approach, mixed models were then constructed as shown in **Table 2**. (Given some missing data, there were initially 175 observations for each model. On the basis of Q–Q plots, one extreme observation was further discarded in the model for Darwinian Divergence, and two in the one for Socio-Cognitive System.) The results show that the type of musical activity had a highly significant effect on each theoretical dimension. Moreover, the background variable of composition experience improved the models for both Strategic and Darwinian Divergence. Finally, jazz experience improved the model for the Socio-Cognitive System dimension. No other fixed effects or interactions could be used to improve the models.

Predicted values from the four models are plotted in **Figure 2**. Beginning with the effects of musical activity, we may note that the first two theoretical dimensions appeared especially suitable for musical activities that tend to take place outside

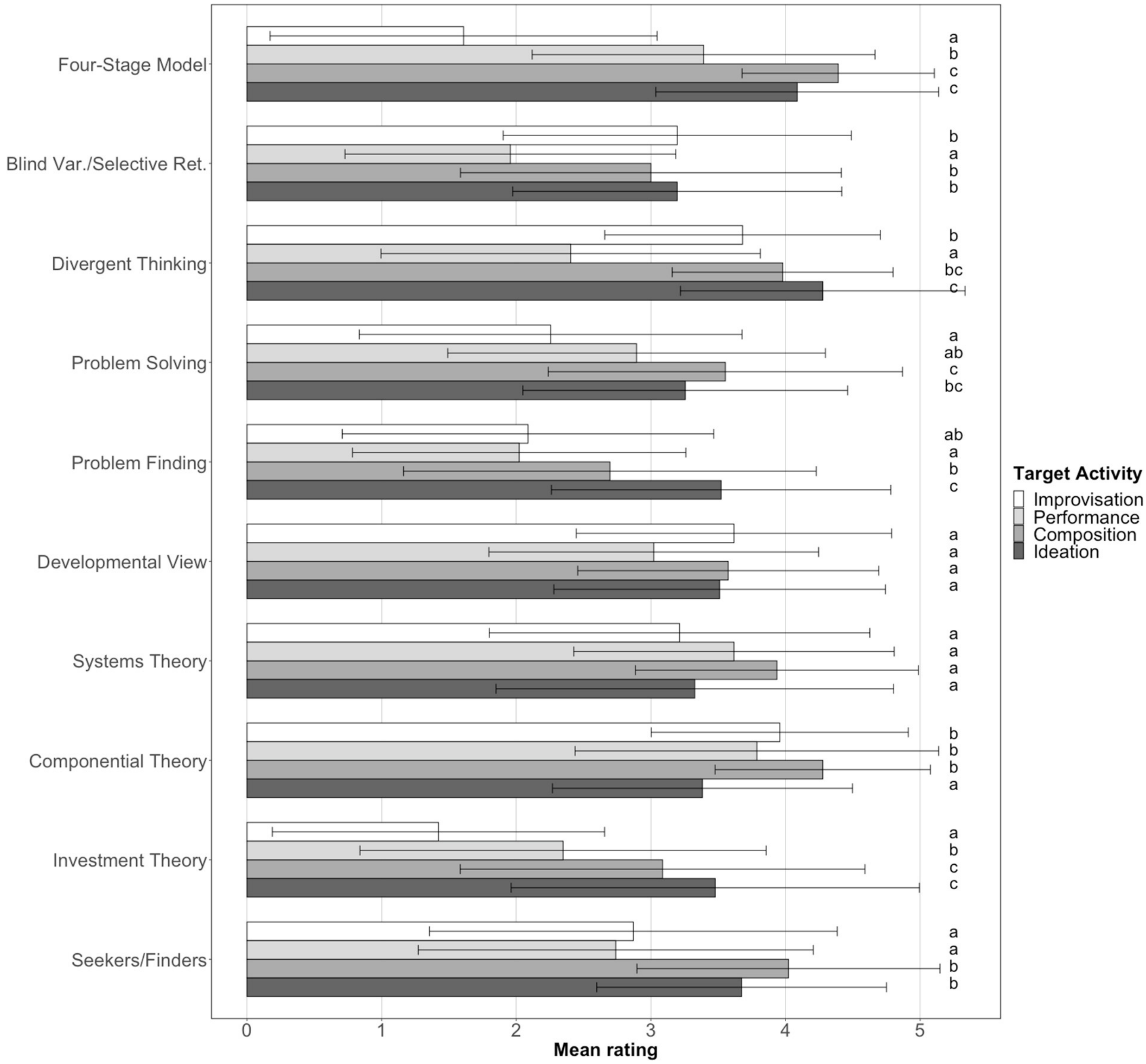

FIGURE 1 | Mean ratings of the 10 theories for the four musical target activities, with standard deviation error bars and compact letter display of pairwise comparisons. Within each theory, activities with the same letter did not differ significantly ($p < 0.05$) from one another in their ratings.

of performance situations. Thus, emphasis on Orderly Process was especially favored in connection with composition and ideation, whereas it was found less suitable for performance and, especially, for improvisation (**Figure 2A**). Similarly, emphasis on Strategic Divergence mostly emerged for ideation and composition, whereas such a perspective was not as favored for performance or improvisation (**Figure 2B**). The two last theoretical dimensions show a different picture: in both cases, one of the musical activities stood out as being the least suitable target to be accounted for in the terms in question. On the one hand, Darwinian Divergence appeared least suitable for musical performance (**Figure 2C**). On the other, the approaches appearing under the Socio-Cognitive System dimension were found least suitable for ideation (**Figure 2D**).

As was made clear above, among the background variables only self-reported composition experience and jazz experience were found to improve the models for the theoretical dimensions. As seen in **Figure 2B**, composition experience decreased the appeal of Strategic Divergence. Thus, even if the strategically rational notions of investment and problem finding might be seen as compatible with (modernist notions of) musical composition, our compositionally active participants seemed opposed to such ideas. Moreover, the lack of interaction with musical activity indicates that their relative resistance to Strategic Divergence not only concerned the activity of musical composition as such, but it appeared across the board for all musical activities. By contrast, composition experience also seemed to make the participants more willing to approach

TABLE 1 | Principal component analysis of participants' ratings for the 10 theories (with varimax rotation).

	Orderly Process	Strategic Divergence	Darwinian Divergence	Socio-Cognitive System	Communality
Problem Solving	0.77				0.60
Four-Stage Model	0.71				0.65
Seekers/Finders	0.66				0.47
Investment Theory		0.76			0.61
Problem Finding		0.60			0.47
Blind Variation/Selective Retention			0.79		0.63
Developmental View			0.64		0.43
Divergent Thinking		0.54	0.50		0.57
Componential Theory				0.77	0.72
Systems Theory				0.76	0.72
Sum of squared loadings	1.627	1.614	1.430	1.225	
Proportion of variance	0.163	0.161	0.143	0.122	
Cumulative variance	0.163	0.324	0.467	0.590	

TABLE 2 | Construction of mixed models for the four dimensions of creativity theories.

		Model fit			Likelihood-ratio rests		
		Marg. R^2	Cond. R^2	*AIC*	χ^2	df	p (> χ^2)
Orderly Process	Random effect	0	0.058	−40.81			
	Target activity	0.299	0.453	−106.49	71.68	3	<0.001***
Strategic Divergence	Random effect	0	0.263	−98.71			
	Target activity	0.249	0.594	−170.71	77.99	3	<0.001***
	Composition exp.	0.291	0.594	−173.04	4.33	1	0.037*
Darwinian Divergence	Random effect	0	0.219	−83.85			
	Target activity	0.297	0.609	−168.75	90.90	3	<0.001***
	Composition exp.	0.351	0.609	−172.93	6.18	1	0.013*
Socio-Cognitive System	Random effect	0	0.317	−63.43			
	Target activity	0.093	0.441	−83.27	25.83	3	<0.001***
	Jazz experience	0.145	0.442	−86.15	4.88	1	0.027*

*Significance levels: ***$p < 0.001$, *$p < 0.05$.*

all musical activities as Darwinian Divergence (see **Figure 2C**). Such results suggest that compositional experience may have familiarized students with free, "blind" generation of musical ideas and materials, unhampered by strategic aims. Similarly, **Figure 2D** suggests that receptivity to ideas of creativity as a Socio-Cognitive System was furthered by participants' jazz experience.

RESULTS II: ARGUMENTATION

Applying Theories to Activities

According to the task instructions, the participants were to defend the "best theoretical perspectives" in their essays. As shown in the left column of **Table 3**, almost half of the 47 participants chose to defend the Four-Stage Model, but Divergent Thinking and Systems Theory were not left far behind. Overall, the numbers of participants choosing to defend a particular theory differed significantly between the 10 theories [$\chi^2(9) = 55.24$, $p < 0.001$]. The three theories that above received the lowest mean ratings were also here least often chosen to be defended. Hence, the two theories that formed the core of the theoretical dimension of Strategic Contribution (i.e., Investment Theory and Problem Finding) were both only chosen to be discussed in four essays. Likewise, even though Blind Variation/Selective Retention was above seen as the central theory for the dimension of Darwinian Divergence, here the theory was only defended by two participants. Notice, then, that while Divergent Thinking in the rating task tended to be enhanced by the striking notions of investment, problem finding, or blind generation, none of the latter ideas were found very appealing for music as such.

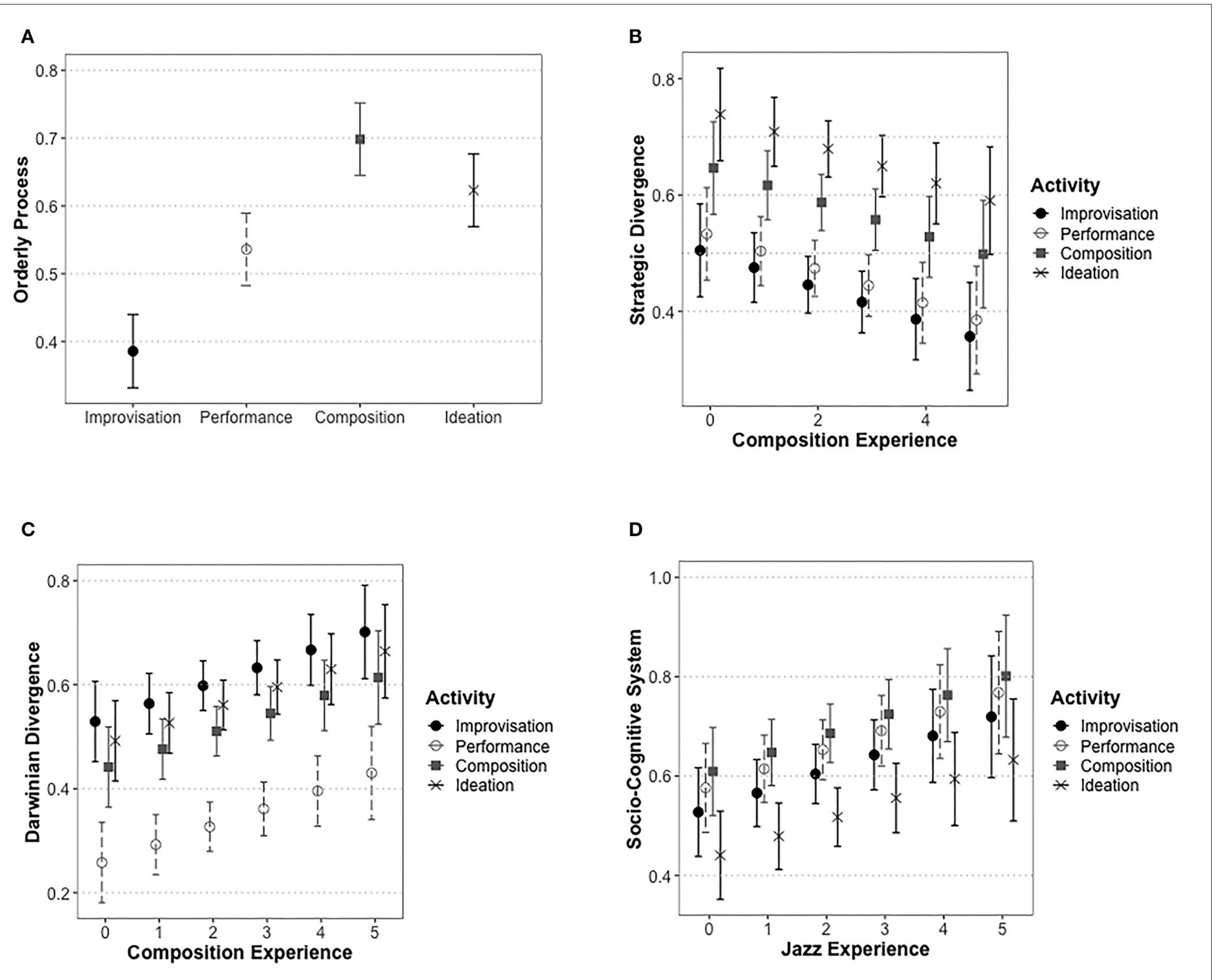

FIGURE 2 | Appreciation of the four theoretical dimensions: predicted values from linear mixed models (with 95% CIs). **(A)** Orderly Process. **(B)** Strategic Divergence. **(C)** Darwinian Divergence. **(D)** Socio-Cognitive System.

The essays were first coded for passages concerning the 10 theories as well as for the four target activities. Using the matrix coding function of NVivo, I thereafter analyzed the overlaps between these two sets of codes (manually correcting the numbers of participants if a single participant showed multiple overlaps between the same codes). The four last columns in **Table 3** show the numbers of participants mentioning any of the 10 theories in conjunction with the four kinds of musical activities. Three of these distributions did not significantly differ from the "chosen to be defended" column, but in the case of composition, there was a significant difference [$\chi^2(9) = 20.85$, $p < 0.05/4$], largely due to the relative success of the Four-Stage Model as an account of compositional work, over and above the other theories.

Argumentation for Theories

The third coding of the essays concerned argumentative content and was carried out in a bottom-up fashion, based on the idea that claims concerning the suitability of theories could be justified in various ways—by appealing to rational reasoning, authority, one's own experience, etc. After an initial coding round, the emerging classes of statements (including longer coherent passages) were reread, attempting to clarify the distinctions between argumentative categories. For instance, the boundary between *generalized illustrations* and (a preliminary category of) *examples* was sharpened by restricting the latter to *particular examples* that focused on individual persons (e.g., Miles Davis) or other historically particular circumstances (e.g., the performance tradition of Russian violinists). Generalized illustrations of the theories, in turn, were lacking in such anchoring to particular individuals or circumstances (e.g., "Perhaps this sort of creative process can be found behind many musical instruments: someone has found a mechanism or approach almost by chance and started to develop it" [participant P12 on Problem Finding]). During this honing process, some preliminary categories were combined: for instance, statements that had first been taken separately as *individually chosen premises* for theorizing (e.g., "the theory should address factors related to the temporal duration of the process such as motivation and environment" [P14]) were combined into the category *theoretical reasoning* that also included more developed conceptual arguments (see an example in **Appendix 2**).

The final coding scheme included four categories of *claims* and nine categories of *justifications* (see **Appendix 2**). Apart from the central *positive claims*, suggesting the suitability of a theory to music or some musical activity, claims also included corresponding *negative claims*, and *theory descriptions* that simply explained the theories or highlighted some of their aspects, as well as *free generalizations* that did not have a clear justificatory function. Justifications, in turn, comprised *generalized illustrations*, appeals to *personal experience*, *particular examples*, *values*, and *authority*, as well as the use of *theoretical reasoning*. In addition, some passages were interpreted as regarding *theoretical complementation* (i.e., relating several theories to one another to strengthen the overall account), as suggestions concerning *application to research* (often stating a personal research interest involving the theory), or as *problematization* in which a given theory was more substantially argued against (instead of a simple negative claim concerning its suitability). This framework necessarily involves some interpretative leeway both in the boundaries between the categories and, especially, in how particular statements were demarcated and how separate arguments were individuated in the texts. In order to alleviate the latter problems, the quantitative parts of the following account are simply based on numbers of participants that were found to use given argumentative means somewhere in their essays in conjunction with given theories or given types of musical activity.

The distribution of the argumentative means in **Table 4** shows that most (45/47) of the participants made direct positive claims regarding the suitability of theories in musical contexts and that the majority (40/47) argued for their views using at least some generalized illustrations. For a simple example of this argumentative strategy, consider the following extract from a musicology student's essay. A positive claim concerning the suitability of the Systems Theory is directly followed by a generalized illustration that simply states the main aspects of the theory in a musical setting:

> [*Positive claim*:] The theory of creativity as a system also well describes working out ideas for music (and composition). [*Generalized illustration*:] Producing a musical idea requires knowledge about the domain, a person who knows things and can for instance develop a new instrument, and an area in which she can further her invention with the help of other colleagues. These, in turn, decide whether the idea is good enough to be published. (P15)

The passage following the positive claim would otherwise be labeled a *theory description*, but the idea of developing a new instrument turns it into a musical illustration of the theory—albeit a highly generalized one. Such generalized illustrations were used for all theories approximately in equal proportion to how often each theory was taken up by the participants. On each row of **Table 4**, the numbers of participants applying the argumentative means in question to the 10 theories has been compared to the total numbers of participants discussing the 10 theories in their essays. On each row, the χ^2 test thus indicates whether the distribution of a particular argumentative means differed significantly from the distribution on the bottom row of the table. (The α levels have been adjusted for multiple comparisons: $\alpha = 0.05/13$). Significant differences from the bottom row were found in the appeals to personal experience and in appeals to values.

First, we may note that more than half of the participants who made references to their own personal experiences did this (at least) in discussions of the Four-Stage Model. Some of them suggested that their own musical orientation ("toward the production side," P14) or, in more essentialist terms, their nature as a "seeker" (P31) or "a logical person" (P13) made the Four-Stage Model relevant to their creative experiences. More often, participants simply mentioned that "the four stages of the theory are easy to discern in my own work" (P27; similarly P2, P9, P26, P32, P43). More specific applications were mentioned as well. One participant referred to having become convinced of the theory by listening to a particular musician (P46), and two mentioned their experiences of creating ideas for music (P36, P45). One of these, a young student of musicology, chose to write her entire essay on the virtues of the Four-Stage Model, explaining each of the four target activities on this basis. She fluently described her own experiences of incubation and illumination in two of the activities that were familiar to her and gave briefer accounts for the two others for which she apparently lacked personal experience. In her longer accounts, she described how ideas for musical compositions or arrangements had just come to her while sitting on a bus or while listening to the radio. In the more experienced end, a 34-year-old student of musicology who reported playing six instruments and working as a musical playschool teacher described her own work with children using the Four-Stage Model. She described a group process of creating music with children in which she felt that her own creative achievement was enhanced by giving the children time to incubate:

> I create a lot of teaching materials: children's songs and rhymes as needed. Some of these come in a moment, but my best products I have managed to get notated and into heavy use through exactly this sort of many-staged process. [...] This fall, in my work at a music playschool, I have tried to give more time to the children's own creative ideas and thoughts. I mean for instance when we made a little Christmas musical with one group. "Giving time" [i.e., incubation] consisted in returning to the ideas in many lessons—in refining and developing them over a longer period of time. (P29)

TABLE 3 | Numbers of participants defending the theories in their essays and applying them to the four musical activities ($N = 47$).

Theory	Chosen to be defended	Applied to target activities			
		Composition	Improvisation	Performance	Ideation
Four-Stage Model	22	20	13	15	11
Divergent Thinking	20	11	14	10	14
Systems Theory	19	12	10	11	7
Componential Theory	15	8	10	10	4
Developmental View	14	8	12	9	6
Seekers/Finders	13	11	10	6	6
Problem Solving	6	5	3	3	2
Investment Theory	4	3	2	3	3
Problem Finding	4	0	2	1	2
Blind Variation/Selective Retention	2	2	2	0	0

TABLE 4 | The distribution of claims and justifications in the participants' essays (numbers of participants applying a given argumentative means for discussing a given theory).

		Four-Stage Model	Divergent Thinking	Systems Theory	Componential Theory	Developmental View	Seekers/Finders	Problem Solving	Problem Finding	Investment Theory	Blind Var./Selective Ret.	Total Participants	χ^2
Claims	Positive claim	21	14	17	14	14	11	3	6	3	3	45	17.66
	Theory description	17	14	12	11	10	6	4	2	2	1	38	13.66
	Free generalization	6	2	10	4	6	4	2	1	1	1	24	12.89
	Negative claim	2	1	1	0	1	1	1	3	0	0	11	11.57
Justifications	Generalized illustration	19	13	12	8	6	7	5	4	3	2	40	10.02
	Problematization	15	7	7	4	6	4	5	3	1	2	33	9.36
	Theoretical complementation	7	7	6	6	3	6	3	3	1	1	25	3.37
	Appeal to personal experience	13	3	2	1	3	5	2	0	0	0	21	27.21*
	Appeal to values	2	10	2	5	0	4	0	5	2	0	20	28.18*
	Appeal to authority	3	4	5	2	5	1	1	1	1	0	18	6.81
	Appeal to particular example	2	1	6	0	2	1	0	0	2	0	16	22.27
	Application to research	4	3	4	3	5	3	1	1	0	2	15	5.21
	Theoretical reasoning	1	6	4	4	1	0	3	2	0	0	14	14.22
	Total participants	26	23	20	18	18	15	11	10	6	6	47	

*Significance levels: *$p < 0.05/13$.*

By contrast, other theories that were often discussed received very few justifications by appeal to personal experience, despite the many positive claims in their favor. As regards Divergent Thinking, two participants briefly mentioned how the theory "corresponds to my experience of improvising" (P15) or how "in my experience, this type of thinking works and yields good results in musical ideation" (P16), while one somewhat unclearly argued for the theory based on her predilection for working processually (P34). For the Developmental View, one of the students simply referred to her "personal experience" (P32), and two others gave examples of their family background that they did not seem to take as equivocal support for the theory. One of these participants wrote that she, as a musical person, was from no musical family herself, but that she had nevertheless been supported in her musical hobby when she had come upon the idea herself (P42). Another found support for the theory in that "I was never encouraged to improvise, which I believe to have affected my current [negative] attitude [toward improvisation]"; at the same time, she also used a counterexample from her family: "Exceptions always exist, and even providing creative space does not always lead to musical creativity. This happened to my sister, who went to piano lessons, children's choir, and to music theory and solfege lessons, but does not do music anymore in any way" (P39).

Turning to the Componential Theory, the only appeal to experience consisted of a single clause in which the participant referred to her experience of rating the theories earlier during the session (rather than to her prior musical experiences). Finally, in the case of Systems Theory, only two participants appealed to their personal experience, both of them using this less as an argument in its own right than to highlight the differences in how creative products could be received in different historical circumstances (e.g., because of their technological underpinnings, "the ideas for music production that we brought to class [in another course assignment] could have been received differently in another era" [P41]). In such cases, one might even contest the interpretation as appeals to personal experience, but the point is that for these theories, no clearer appeals to personal experience were made at all. This is perhaps understandable: particular, lived experiences as such may not be enough to support ideas of multicomponent systems, theories based on statistical observations (Developmental View), or ones that otherwise require judging the divergence or usefulness of ideas or products from an "outsider" perspective.

The other argumentative means with a unique distribution of participants between the theories was appeal to values (see **Table 4**). Here, the two favorite theories in the essays showed a picture quite opposite to what was above seen with personal experiences. While the Four-Stage Model was only twice justified by normative appeal to values (e.g., "A fine result [...] requires preparation, mental processing etc." [P44]), half of the 20 participants appealing to values used this strategy in connection with Divergent Thinking. According to these participants, musical ideation (P19) or composition (P34) can be "at its best" when the creator works divergently: "in musical ideation, diverting from mainstream thought can be essential" (P19), and "new ideas are needed for music to be reformed" (P47). A 31-year-old popular music guitarist, close to graduation in musicology, went into more depth about the "essential" role of divergent thinking in the creative process:

> There is the danger that you cannot decide which idea to start working on, and that you instead even-handedly throw around different ideas. In order to progress, it is essential that you have an initial idea that is then subjected to incoherence. [...] It is not so important what the original idea was, but it is important to begin from somewhere. (P12)

Some of the participants also showed awareness of how their own aesthetic values may have affected their attitude toward Divergent Thinking: "I may have chosen this theory, because I myself value creative ideas that are also practical" (P43). In other cases, the authors anchored their own value judgments in beliefs about other people's aesthetic values: divergent thought can thus be "important if the goal of the composers is to get credit for their creativity in a community" (P10). Indeed, theorizing about Divergent Thinking often seemed to require addressing the experiences of other people: "the divergent thinker should also show some practical thinking, so that the excessive originality of ideas does not begin to erode their value: [...] when originality transcends the understanding of the audience, the value ascribed to the work by the audience begins to descend" (P14). In the following example, another student of musicology similarly made value judgments of his own, first about divergent thought in composition and then in improvisation, each time bolstering his own value judgments ("it may be beneficial," "may be a double-edged sword") by referring to the aesthetic values of the public:

> In composition, it may be beneficial for the composer to think divergently. This is because the public often appreciates surprise in musical works—albeit too much surprise [...] in composition may also be disadvantageous. [...] As in composition, divergent thinking may also be a double-edged sword in improvisation. Too much "jazzing" by, say, a dance-band guitarist may lead to falling out of the audience's favor. However, some also prefer surprisingness and unconventionality in improvisation. (P4)

Argumentation Regarding Musical Activities

Running a similar analysis of argumentative means in connection with the four musical target activities led to a simple observation. For most argumentative means, the distribution of participants using the argumentative strategy in the four activities did not significantly differ from the overall numbers of participants discussing these activities (43 improvisation; 46 composition; 41 performance; 33 ideation). The exception was *problematization* for which the distribution of participants was heavily biased. Among the 30 respondents using problematization, 19 did this while applying theories to improvisation, whereas only 9 problematized theories in composition, 3 in performance, and 6 in ideation [$\chi^2(3) = 16.57$, $p < 0.05/13$]. Interestingly, 11 of the critical responses regarding improvisation were specifically about the Four-Stage Model, 10 of them pointing out problems in fitting something as fleeting as improvisation into the temporally extended framework of the theory. Some saw a problem in the first stage of preparation in which a problem is defined: "if by improvisation we mean expression taking place in a given moment of time, no first-stage problem actually exists" (P36); "you cannot prepare if you live in the moment" (P3). More often, the trouble seemed to lie in the incubation stage of the model: "there is no time for incubation in momentary discovery" (P10, similarly P3, P4, P20, P29). Along similar lines, one student of musicology remarked that applying the Four-Stage Model to improvisation would require either "running through the [four-stage] process very rapidly, leaving out certain stages, or confining oneself to only the last two stages (and thus improvisation would be 'illumination' or verification of what has previously been absorbed)" (P8).

While improvisation most often created problems for the Four-Stage Model, each of the other theories were problematized once or twice as applied to improvisation (with the exception of the Investment Theory that simply appeared to be ignored as irrelevant for improvisation). A heavy-metal guitarist, for instance, saw the Systems Theory as "leaving a cold view of improvisation" as it ignores "little pitch-level details" and generally "leaves in the dark the individual that is often central in improvisation" (P41).

Overall, students' problematizations revealed a range of different conceptualizations regarding improvisation. Discussing the Systems Theory, a classical violinist expressed the opinion that "purely expressive improvisation [...] is not even meant to be linked to a certain tradition, its products often not meant to be preserved for posterity" (P38). Quite to the contrary, a 33-year-old student of music education with multi-instrumental skills (nine instruments) and extensive improvisation experience saw Divergent Thinking as problematic for improvisation exactly because improvisation is often subject to traditional constraints (see **Appendix 2**). For another example of opposing views, one participant said she "feels that in improvisation a problem is not solved, but rather found" (P32), while another thought that "problem finding requires profound thinking of the matter" which is not possible in improvisation (P12). The participants' prolematizations thus show how improvisation often required stretching or reinterpreting the theories, leading the participants to different directions. One music education student in her senior year admitted that she had been unable to find "the most explanatory theory" for improvisation, because the notion of improvisation itself is slippery, lacking a clear definition. For her, this state of affairs was supported by her own musical experience: "sometimes, improvisation springs from a primitive unconscious, while sometimes it arises on the basis of certain musical models" (P43).

Combining Theories

In their essays, the participants chose to defend an average of 2.5 theories (SD = 1.0), and the chosen combinations of theories formed relatively distinct types. A hierarchical cluster analysis of the defended theories yielded a solution in which the first main branch included essays defending the Four-Stage Model and/or Divergent Thinking (two subbranches of 13 and 17 participants corresponding to the absence and presence of Systems Theory, respectively). Given the role of personal experiences in justifying the Four-Stage Model and the role of values in defending Divergent Thinking, this branch was characterized by a "subjective" argumentative style. The second main branch de-emphasized both the Four-Stage Model and Divergent Thinking, and presented more "objective" argumentative approaches instead. Its two subbranches focused on psychological explanations, on the one hand (6 participants choosing Seekers/Finders and/or Developmental View), and systems accounts, on the other (11 participants choosing Componential Theory and/or Systems Theory).

Whether it was an artifact of the study design or not, by choosing such combinations of theories most students seemed inclined toward a certain theoretical pluralism: "creativity can be approached from many perspectives" (P44). While the need for several theories was implicit in most participants' multiple choices of theories, some of them also presented explicit arguments regarding theoretical scope: "even the most interesting theoretical perspective is not necessarily suited for understanding all areas of musical creativity" (P42). Some of the students simply argued that "by combining these perspectives according to situation, we can reach a fairly good understanding of creativity as a process" (P10), but others draw the line between musical activities. For instance: "composition and musical ideation are close to one another as phenomena, whereas improvisation and musical performance require a different theoretical approach" (P11). Theories were frequently discussed as if they allowed to "put the focus on" (P46) various aspects of a phenomenon that cannot quite be grasped in its totality in terms of one theory only. A handful of students also argued for the multicomponent or systems views on the grounds that they are "more comprehensive" than other theories (P25) and "bring together aspects from several theories" (P38).

An elaborate example of such scope argumentation appeared in the essay by a 27-year-old graduate student of musicology, known as a competent jazz pianist. After a detailed argument for the Componential Theory—itself a pluralistic combination of aspects—he argued that the "downside of a model that applies to [several] different methods of music making is that it is broad by necessity" (P5). Hence:

> Due to the vast number of different tasks and methods involved [in] music making, it is my view that no one theory of creativity can describe it perfectly. Instead, the main music-making processes can be seen as being composed of a variety of smaller scale processes, and these processes have their own sub-processes. (Meanwhile, the boundaries between simultaneous processes are unclear and sometimes disappear altogether, making this an even trickier subject to tackle.) Which model we use to describe music making should depend on how close we "zoom in" on each process. The component theory works well on a broad scale, with many of the other theories being relevant with more specific processes. (P5)

Thus, in particular:

> If we are to look more closely at the domain-relevant skills component in the component model of creativity, we can see that the acquiring of these skills is in itself not entirely free of creativity [...]. [The acquisition] of domain-relevant skills is often a process of problem solving, which can also include its own kind of creativity [...]. Likewise, divergent thinking clearly falls within the "creativity-relevant skills" component, a skill that can be used in most aspects of music making, though maybe not on a regular basis. (P5)

Accounts such as this suggest treating theories of creativity less as mutually exclusive alternatives, and more as useful ideas that may be combined in various ways in order to grasp different facets of a more complex phenomenon. In the excerpt seen above, the student goes still further, in effect working out a *reinforcement* relation between theories in which one theory provides the "rationale" for another (see Laudan, 1977).

DISCUSSION

In the introduction, I noted that while theories of creativity have been applied in some areas of music research, other music scholars have either ignored such theories or even opposed them with skepticism. Assuming that most theories of creativity have been meant to cover musical creativity, too, my aim in this study was to analyze musically active and relatively well-informed adults' understanding of such theories in order to gain an overview of potential stumbling blocks in this domain. In the study, higher-education music students appraised general theories of creativity as accounts of four types of musical target activities—composition, improvisation, performance of composed music, and ideation (i.e., creating ideas for making music). These activities do not, of course, cover all possible forms of musical creativity (e.g., creativity in listening) but were chosen to present some variety that might help in assessing the context dependence of the theories. Based on a classification of creativity theories in a standard reference work (Kozbelt et al., 2010), a representative sample of 10 theory descriptions was subjected to music students' ratings. The participants were also asked to choose the "best theoretical perspectives" and to argue for them in written essays. The focus on musically active people's understanding of explicitly formulated scholarly theories of creativity is rather unique, given that most research about peoples' conceptions regarding creativity has focused on informal beliefs. I will now review the findings in response to the four research questions presented in the beginning.

The first half of the first research question asked whether the judged suitability of theories would differ between the target activities. Significant differences between the activities were found for eight of the theories, and they mostly had to do with problems of accounting for musical improvisation or performance. To condense the data, a principal component analysis of participants' theory ratings was carried out. This yielded four theoretical dimensions, respectively emphasizing creativity as an Orderly Process, as Strategic or Darwinian Divergence, and as a Socio-Cognitive System. Linear mixed models showed each of these dimensions to be dependent on the target activities. The dimensions of Orderly Process and Strategic Divergence, in particular, were favored when accounting for composition and ideation, but not so much in the contexts of performance and improvisation. The dimension of Darwinian Divergence, dominated by the Blind Variation/Selective Retention theory (Campbell, 1960; Simonton, 1997, 1999, 2010, 2015), was found least appropriate for the performance of composed music. These results were complemented by how the participants in their essays chose somewhat different theories to account for various target activities. In particular, Wallas's (1926) Four-Stage Model of creativity emerged as a particularly suitable way of accounting for composition. Indeed, most of the participants who chose to defend the Four-Stage Model in their essays defended it at least as an account of composition. This resonates with some previous research in which the Four-Stage Model has been used to account for both music students' (Burnard and Younker, 2004; Chen, 2012) and professional composers' actual compositional processes (Katz, 2012; Katz and Gardner, 2012). At the same time, the theory ratings indicated appreciable problems in applying the Four-Stage Model to improvisation. All in all, the results indicate that the students viewed the theories as relatively context-dependent, and in this sense, not as very "general" theories. Based on the ratings, the exceptions seemed to be the Developmental Theory, Systems Theory, and, perhaps, Componential Theory, all of which received high ratings across the target activities. Other theories, however, seemed to encounter problems especially with the in-time processes of musical performance and/or improvisation.

The latter half of the first research question addressed whether theory appraisal would also be influenced by the "characteristics of the individuals who make the choice" (Kuhn, 1977, p. 324). In this regard, most background variables, including gender, personality, and years of musical activity, showed no systematic effect on participants' ratings. However, composition and jazz experience apparently affected their views. On the one hand, participants' receptivity to creativity as a Socio-Cognitive System was furthered by their experience of playing jazz music. This could mean that experience in improvisatory music-making is associated with the emphasis of domain-specific knowledge and skills (mentioned in both of the relevant theoretical summaries), with awareness of the relevance of task motivation, and with understanding of how creative actions are received by other members of the field. On the other hand, composition experience decreased participants' approval of creativity as Strategic Divergence but increased their approval of the dimension of Darwinian Divergence. A possible interpretation would be that solitary compositional work may have accustomed students to thinking about creativity as playful engagement with musical materials, unhampered by strategic aims. Indeed, in the essays the Darwinian idea of Blind Variation and Selective Retention was never discussed as an evolutionary account of creative career trajectories (see Simonton, 1997), but rather as an account of particular creative processes (see Johnson-Laird, 2002). The few students who mentioned the theory saw blind generation as akin to free, imaginative play, or "wild experimentation" (P2), which contrasts both with the idea of orderly processes and with strategic planning. The finding that compositional experience increased receptivity to such playful attitudes indicates a stark contrast to 20th-century's modernist notions of systematic pre-compositional planning (e.g., Stockhausen, 1964; Boulez, 1981; Xenakis, 1990), and to ideas of creativity as anxious struggle against predecessors (discussed with the students during the course: Straus, 1990).

The second research question was about whether students' argumentative strategies in the essays would vary between the theories and/or between the musical target activities. For addressing the question, nine classes of justificatory strategies were identified in the students' texts, subsequently observing to what extent these different lines of argument appeared in connection with the 10 theories. For two of the argumentative means, the distribution of participants applying the strategy in the 10 theories differed significantly from the distribution of participants discussing the theories. First, references to participants' own personal experiences were particularly often combined with the Four-Stage Model. This might be explained by introspective access to the characteristic incubation–illumination sequence of the theory: it may be almost too easy to introspectively apply the sequence to episodes of one's own creative experiences. Patterns of action that can relevantly be described by the model can be a part of the life-worlds of creative persons themselves, as also indicated by Katz and Gardner's (2012) use of the theory in accounting for composers' processes on the basis of interviews. Second, in comparison to other justificatory strategies, references to values were significantly emphasized in accounts of Divergent Thinking. In other words, arguments for Divergent Thinking simply tended to emphasize the special value or essential role of divergent ideas for musical creativity. It may be noted that in the written summary used for the study, the core idea of the theory might not seem much more than a value judgment in itself: "It has been argued that the more remote an idea is [...], the more likely it is to be original and potentially creative" (Kozbelt et al., 2010, p. 29). Hence, many of the students' arguments in this category could be seen as simply affirming a definition of creativity as divergent thought and assuming that creativity is valuable.

A similar analysis regarding the uses of justification for the four musical target activities yielded one central finding: the argumentative strategy of problematization was particularly accentuated in the case of improvisation. In the introduction, we saw that while research in composition has frequently referred to general theories of creativity, such references have been all but nonexistent in some important anthologies of improvisation research. The argumentation analysis suggests that the participants of the present study may have felt similar problems in applying theories of creativity to improvisation. To be sure, a large share of the problematizations concerned the Four-Stage Model (e.g., claiming the notion of incubation to be inappropriate for improvising in the moment). In the creativity literature, such problems are well-known: Fischer and Amabile (2009), for instance, distinguish multistage "compositional creativity" from "improvisational creativity" in which the creative process "is one single step" (Fischer and Amabile, 2009, p. 16). In the ratings, however, not only the Four-Stage Model but also Problem Solving, Problem Finding, and Investment Theory were rated especially low for improvisation (see **Figure 1**). Consequently, the two strongest theoretical dimensions in the above principal component analysis, too, were de-emphasized for improvisation (see **Figures 2A,B**). It may have appeared somewhat contrived to the participants to interpret the continuous activity of improvisation as solving or finding discretely identified problems (see Mazzola and Cherlin, 2009). Of course, this does not rule out the possibility that other theoretical accounts might more successfully interpret improvisation in related terms—say, as an activity of solving problems of interactive coordination (Saint-Germier and Canonne, 2020; see also Sawyer, 2003).

The third research question asked which of the theories the students might see as particularly suitable for music. The highest mean ratings were received by Amabile's (1996) Componential Theory which was apparently deemed quite suitable for all of the target activities. In the essays where the students could freely choose their favorite theories, the three theories most often defended were the Four-Stage Model (47% of the participants), Divergent Thinking (43%), and Systems Theory (40%). Notice that while the first and last of these theories also align with the theoretical dimensions of Orderly Process and Socio-Cognitive System identified through the ratings, the theory of Divergent Thinking appeared in the ratings in two different dimensions, as either Strategic or Darwinian Divergence. Interestingly, most of the other theories loading on these two dimensions were only rarely chosen to be defended by the participants in their essays. It seems, then, that the students were unwilling to embrace explicitly strategic thinking (Investment Theory, Problem Finding), and perhaps even more unwilling to defend processes of Blind Variation/Selective Retention in order to account for the origin of divergent thought. Simply put, questions of creative intention vs. randomness rarely emerged as the main concern of the participants' arguments. Avoiding notions of strategic investment or defiance (see Sternberg, 2018) as well as non-strategic Darwinian thinking, the students more often chose to account for musical creativity as individual staged processes, as valuable divergence, or as complex systems that are either internal or external to the creative individual.

Finally, the fourth research question addressed the students' conceptions of theories and theory choice in general. In their essays, none of the students—despite reading Frith (2012) during the course—voiced anything like theory skepticism that would dismiss general theories of creativity across the board. (Given their oftentimes harsh criticism of individual theories, it does not seem likely that this was due to ingratiation with their teacher.) Perhaps less surprisingly, none of the students either proposed full-scale reorientation of the theoretical domain (theory revisionism). Instead, most of the students tended toward moderate forms of theory eclecticism, often choosing to argue for some combination of two or three theories. Many of them also explicitly argued that musical creativity cannot be accounted for just by a single theory. Accordingly, theories of creativity were treated not so much as mutually exclusive alternatives, but rather as spotlights illuminating the phenomenon of musical creativity from various angles. This eclectic approach is similar to the basic orientation of Componential Theory that indeed received the highest mean ratings in the study. It should be noted, though, that the concise theoretical summaries used in the present study may have supported an eclectic approach to theory choice and even favored some theories. In particular, whereas Amabile's (1996) full account of the Componential Theory also includes a model of creative response generation couched in information-processing terms, and even principles for predicting levels of creativity, the theoretical summary used in the present study was theoretically less precise, simply listing the three components of the theory (domain-relevant skills, creativity-relevant skills, task motivation). This might help explain the high ratings: the summary might simply have been accepted as a bazaar of useful-sounding requirements for creativity, leaving room for the students' own theoretical thinking to connect the dots. In the field of music education, a similar, informally eclectic approach is present in Webster's (1990) model of creative thinking in music that combines ideas related to product intentions, enabling skills and conditions, and a core consisting of movement, in Wallas's (1926) stages, between divergent and convergent thinking.

Notice that while many of the theories discussed in this study could be seen as relatively complex belief systems (at least in their original contexts), the basic insights of at least some of them might also well be expressed as simple definitions (e.g., "creativity is divergent thinking" or "creativity is problem solving"). The students' theory eclecticism might thus be taken to demonstrate that many combinations between such rudimentary definitions are not contradictory or meaningless, but rather allow multi-perspectival views to the phenomenon at hand. In this sense, the students' individual approaches to theories sometimes resembled more comprehensive scholarly definitions of creativity that cover various aspects such as aptitude, process, environment, and social recognition (e.g., Plucker et al., 2004). Interestingly, even researchers' multi-aspect theoretical models of creativity sometimes do not amount to much more than definitions: a case in point could be Webster's (1990) abovementioned model of creative thinking in music. To what extent theories of creativity in general tend to collapse to definitions would require another study. Here, I just want to note that a definitory approach to theorizing about creativity might sometimes just serve the role of specifying the topic of investigation. For instance, in saying that "creativity is problem solving," we might not intend to be making an empirically falsifiable claim about some independently identifiable states of affairs (referred to by the term "creativity"). Instead, we might just be suggesting how to identify instances of creativity in the first place. Accordingly, the participants in the present research seemed to use the theories more often to identify a phenomenon of interest than to explain one. Thus, in recording a person's acknowledgment of a definitory theory (e.g., "creativity is problem solving"), we might not yet have covered much of her belief system concerning creativity. Such a belief system—an "implicit theory" if you will—would also include aspects of how she understands problem solving and its role for some phenomena of interest, how she constructs her own identity in relation to such activities, and so on. As seen in the introduction, personal belief systems about creativity should not be equated with summaries of beliefs on a group level, but they should also not be equated with the scholarly theories endorsed by the individual. Quite often, the latter might just serve to broach a topic.

What has been said above also reveals a lot about the students' criteria for theory choice. Recalling Kuhn's (1977) list of criteria for theory choice, we may first take up the important question regarding accuracy. In the essays, 85% of the students used generalized illustrations to justify their favored theories, while agreement with other observations or knowledge was not quite as common: 45% of the students appealed to personal experience, 38% to authorities, and 34% to particular examples. As these categories imply, "factual" support for the theories was mainly sought through examples—many of which were drawn from the students' own experiences. In science education, students' justifications may appear inappropriate if they are based on personal experiences (see e.g., Sampson and Clark, 2008), but in the arts this should not be as clear, as it would rule out many aesthetic arguments. In any case, the notion of accuracy at play here has less to do with explanatory adequacy than with just some sort of "fit" or "coverage"—finding examples that would fit a given theoretical description of creativity. In other words, theories were often treated simply as "ideas with evidence" (see Dagher et al., 2004). It may be difficult to draw a sharp distinction between accuracy in this loose sense and some loose criterion of fruitfulness. Apart from the suggested applications of the theories to music research (32%), students' generalized illustrations often included brief hypothetical examples of what someone could do musically in accordance with a given theory.

Other possible criteria for theory appraisal were applied less often. While the task instructions prompted the participants to address issues of theory scope—this was already implicit in asking for separate ratings for different target activities—only a few participants in their essays explicitly mentioned broad scope as an argument for a particular theory. Problems of narrow scope were frequently acknowledged when a given theory was deemed unfit for a certain target activity, but such problems were solved by eclectically turning to other theories. Accordingly, issues of consistency were mostly apparent as theory complementation: 53% of the participants commented on how theories might support one another in the task of accounting for musical creativity as a broader phenomenon. As shown by the example of theory reinforcement in the end of the results section, this was sometimes done with great ingenuity. By contrast, questions of the theories' internal consistency or their consistency with other beliefs were not discussed in the essays. Likewise, concerns for simplicity were hardly mentioned at all. These findings are thus in line with Furnham's (1988) conclusions in his study concerning lay theories: "Few lay people undertake a formal evaluation of theories, preferring a more pragmatic evaluation" (Furnham, 1988, p. 226). The students' thinking was driven by pragmatic concerns of finding fitting examples and fruitful contexts of application, but they largely ignored formal aspects that might affect theory choice—such as arguments for broad scope, simplicity, and consistency.

The study undertaken here has some obvious limitations, chief among which is perhaps the range of theories chosen to be addressed. In designing the study, I relied on what seemed one of the most balanced and wide-ranging chapter-length accounts of creativity theories available at the time (Kozbelt et al., 2010), but this selection has just scratched the surface (for a recent review, see Kaufman and Glăveanu, 2019). In the field of music, future work might especially need to pay more attention to theories with an eye on the embodied and socially distributed aspects of creative processes (see Linson and Clarke, 2017; van der Schyff et al., 2018; Schiavio et al., 2020). Another potentially problematic aspect, pointed out by two anonymous reviewers, is to what extent the results simply reflect the students' understanding or recall of course content. Quite obviously, some of the students may have studied the handbook chapter more carefully than others in the beginning of the course, thus "knowing" the theoretical context better than others who had to rely more on the short descriptions provided. Consequently, some of the theories may even have been misunderstood by some of the participants. While this is a genuine methodological issue, it also arguably reflects the situated character of the whole undertaking. In asking people to appraise theories of creativity, we are relying on the participants' individual points of view nurtured by their experiences and understandings regarding creativity, and it seems impossible to except the theories themselves from such "subjective" understandings. As any scholarly dispute about theories would suggest, theories themselves can be understood in different ways, and in the present context I have simply attempted to make such varying understandings more transparent by also engaging with the qualitative differences inherent in the participants' responses.

In closing, let us wrap up the challenges that the present research might raise to creativity research. Despite the lay character of their justifications, the participants were quite experienced musically, most of them reported rich creative activities, and they were all studying musicology or music education in the university, many at graduate level. In this sense, their views should arguably be taken more seriously than simply dismissing them as inaccurate if they do not align with research (cf. Introduction). Consider the case of improvisation. Jordanous and Keller (2012) have previously demonstrated that written accounts regarding improvisation might only emphasize a part of the concepts that characterize texts on creativity. The present results complement such findings by relating the problems of conceptualizing improvisation to theories of creativity. While some of the problems may be well-understood—e.g., the problems that the Four-Stage Model would have as a theory of improvisation—the study also reveals other aspects. The four theories that were least often chosen as favorite accounts of improvisation in students' essays—Blind Variation/Selective Retention, Investment Theory, Problem Finding, and Problem Solving—were also the least often defended theories overall. This suggests that improvisation may hold some keys to the intuitive acceptability of these theories. Of course, it remains open to the creativity theorist to hold that some such theories are not even intended to capture practitioners' beliefs about musical creativity.

Accordingly, such potential distance between well-received theories and musical practitioners' accounts of creativity should urge theorists to clarify on what basis their theories should be embraced. Or, in general, we may ask what theories of creativity are theories about, and in what sense they are theories. Supposing, for instance, that scientific theories should function as solutions to empirical problems (Laudan, 1977), the students' arguments analyzed in the present study would seem to fail to demonstrate a "scientific" use of the theories. Rather than as solutions to problems, theories were often used merely as descriptions that could fit some phenomena that the writer was familiar with. For the creativity theorist, possible responses might be either to show how her theory can be made to solve genuine problems, or to reject the suggested requirement for problem solving and explain what alternative functions the theory might serve. Similar points could be made regarding possible criteria for theory choice. In a sense, the pragmatic character of students' theory appraisals is not far from what was informally observed about music researchers' typical use of creativity theories in the introduction: in these applied contexts, explicit arguments regarding choice between theories of creativity are rarely put forward. For the creativity theorist, this poses challenges, one of which is not to propose yet a new theory of creativity without clearly articulating what its scope is supposed to be, and on what grounds it should be considered as rival to certain other theories.

At the outset, we saw that research on informal conceptions of creativity has been motivated by the idea that we should seek to align practitioners' views with research-based knowledge (Andiliou and Murphy, 2010). If so, the obvious step to take should be to actually engage students and practicing professionals with research on creativity. In the present study, I chose to do this with higher-education music students, but without assuming that the primary task was to "correct" them in their possible misconceptions. Instead, I have assumed that the students possess a wealth of first-hand experience in musical creativity and that their theory appraisals might thus tell us something important about the scope and nature of theories of creativity. If we are interested in fostering creativity in higher music education, we should arguably encourage students to engage with these theories with a similar sense of creative possibility that we expect to find in their music. Whatever philosophical conceptions we might hold regarding theory choice in research, as educators we probably should have no reason to argue against the students' pragmatic understandings of which ideas "work best" in relation to their own culturally specific and situationally changing creativities.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the dataset includes qualitative case descriptions, with information that could reveal the identity of the participants. Requests to access the datasets should be directed to erkki.s.huovinen@gmail.com.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.612739/full#supplementary-material

REFERENCES

Ainsworth-Land, V. (1982). Imaging and creativity: an integrating perspective. *J. Creat. Behav*. 16, 5–28. doi: 10.1002/j.2162-6057.1982.tb00319.x

Amabile, T. M. (1996). *Creativity in Context: Update to the Social Psychology of Creativity*. Boulder, CO; Oxford: Westview Press.

Andiliou, A., and Murphy, P. K. (2010). Examining variations among researchers' and teachers' conceptualizations of creativity: a review and synthesis of contemporary research. *Educ. Res. Rev.* 5, 201–219. doi: 10.1016/j.edurev.2010.07.003

Bailes, F., and Bishop, L. (2012). "Musical imagery in the creative process," in *The Act of Musical Composition: Studies in the Creative Process,* ed D. Collins (Farnham: Ashgate), 53–77.

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw*. 67, 1–50. doi: 10.18637/jss.v067.i01

Bazeley, P. (2018). *Integrating Analyses in Mixed Methods Research*. London; Thousand Oaks, CA; New Delhi; Singapore: Sage. doi: 10.4135/9781526417190

Bennett, J. (2012). "Constraint, collaboration and creativity in popular songwriting teams," in *The Act of Musical Composition: Studies in the Creative Process,* ed D. Collins (Farnham: Ashgate), 139–169.

Boden, M. A. (1990). *The Creative Mind: Myths and Mechanisms.* New York, NY: Basic Books.

Boden, M. A. (2010). *Creativity and Art: Three Roads to Surprise*. New York, NY: Oxford University Press.

Borgo, D. (2007). *Sync or Swarm: Improvising Music in a Complex Age*. New York, NY; London: Continuum.

Botella, M., Glăveanu, V., Zenasni, F., Storme, M., Myszkowski, N., Wolff, M., et al. (2013). How artists create: creative process and multivariate factors. *Learn. Individ. Differ*. 26, 161–170. doi: 10.1016/j.lindif.2013.02.008

Boulez, P. (1981). "Le système mis à nu," in *Points de Repère,* eds P. Boulez and J.-J Nattiez (Paris: Christian Bourgois éditeur), 127–140.

Brown, A. R., and Dillon, S. (2012). "Meaningful engagement with music composition," in *The Act of Musical Composition: Studies in the Creative Process,* ed D. Collins (Farnham: Ashgate), 79–109.

Buelow, G. J. (1990). Originality, genius, plagiarism in English criticism of the Eighteenth Century. *Int. Rev. Aesthet. Sociol. Music* 21, 117–128. doi: 10.2307/837018

Burnard, P. (2012a). *Musical Creativities in Practice*. Oxford: Oxford University Press. doi: 10.1093/acprof:oso/9780199583942.001.0001

Burnard, P. (2012b). "The practiced of diverse compositional creativities," in *The Act of Musical Composition: Studies in the Creative Process,* ed D. Collins (Farnham: Ashgate), 111–138.

Burnard, P., and Younker, B. A. (2004). Problem-solving and creativity: insights from students' individual composing pathways. *Int. J. Music Educ.* 22, 59–76. doi: 10.1177/0255761404042375

Campbell, D. T. (1960). Blind variation and selective retention in creative thought as in other knowledge processes. *Psychol. Rev*. 67, 380–400. doi: 10.1037/h0040373

Campbell, P. S. (2009). "Learning to improvise music, improvising to learn music," in *Musical Improvisation: Art, Education, and Society,* eds G. Solis and B. Nettl (Urbana; Chicago, IL: University of Illinois Press), 119–142.

Chan, D. W., and Chan, L. (1999). Implicit theories of creativity: teachers' perception of student characteristics in Hong Kong. *Creat. Res. J*. 12, 185–195. doi: 10.1207/s15326934crj1203_3

Chen, J. C. W. (2012). A pilot study mapping students' composing strategies: implications for teaching computer-assisted composition. *Res. Stud. Music Educ.* 34, 157–171. doi: 10.1177/1321103X12465515

Clarke, E., Doffman, M., and Lim, L. (2013). Distributed creativity and ecological dynamics: a case study of Liza Lim's "tongue of the invisible". *Music Lett.* 94, 628–663. doi: 10.1093/ml/gct118

Clarke, E. F. (2012). "Creativity in performance," In Hargreaves, D. Miell, and R. MacDonald (eds) *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance, and Perception*, (Oxford; New York, NY: Oxford University Press), 17–30.

Clarke, E. F., Doffman, M., Gorton, D., and Östersjö, S. (2017). "Fluid practices, solid roles? The evolution of Forlorn Hope," in *Distributed Creativity: Collaboration and Improvisation in Contemporary Music,* eds E. F. Clarke and M. Doffman (New York, NY: Oxford University Press), 116–135. doi: 10.1093/oso/9780199355914.003.0009

Collins, D. (ed.) (2012). *The Act of Musical Composition: Studies in the Creative Process.* Farnham: Ashgate.

Costa, P. T. Jr., and McCrae, R. R. (2014). "The NEO inventories," in *Personality Assessment, 2nd Edn,* eds R. P. Archer and S. R. Smith (New York, NY; London: Routledge), 223–256.

Cropley, D. H., Patston, T., Marrone, R. L., and Kaufman, J. C. (2019). Essential, unexceptional and universal: teacher implicit beliefs of creativity. *Think. Skills Creat.* 34, 1–11. doi: 10.1016/j.tsc.2019.100604

Crow, B. (2008). Changing conceptions of educational creativity: a study of student teachers' experience of musical creativity. *Music Educ. Res.* 10, 373–388. doi: 10.1080/14613800802280126

Csikszentmihalyi, M. (1997). *Creativity: Flow and the Psychology of Discovery and Invention*. New York, NY: Harper Perennial.

Dagher, Z. R., Brickhouse, N. W., Shipman, H., and Letts, W. J. (2004). How some college students represent their understandings of the nature of scientific theories. *Int. J. Sci. Educ*. 26, 735–755. doi: 10.1080/0950069032000138806

Daniel, R. (2020). The creative process explored: artists' views and reflections. *Creat. Indus. J.* 1–14. doi: 10.1080/17510694.2020.1755772

de Bono, E. (1992). *Serious Creativity: Using the Power of Lateral Thinking to Create New Ideas*. New York, NY: Harper Business.

Dean, R. T., and Bailes, F. (2016). "Cognitive processes in musical improvisation," in *The Oxford Handbook of Critical Improvisation Studies, Vol. 1*, eds G. E. Lewis and B. Piekut (New York, NY: Oxford University Press), 39–55.

Deliège, I., and Richelle, M. (2006). "Prelude: the spectrum of musical creativity," in *Musical Creativity: Multidisciplinary Research in Theory and Practice,* eds I. Deliège and G. A. Wiggins (Hove; New York, NY: Psychology Press), 1–6. doi: 10.4324/9780203088111

Dennett, D. (2001). "Collision detection, muselot, and scribbles: some reflections on creativity," in *Virtual Music: Computer Synthesis of Musical Style,* ed D. Cope (Cambridge, MA: The MIT Press), 283–291.

Digman, J. M. (1990). Personality structure: emergence of the Five-Factor Model. *Annu. Rev. Psychol.* 41, 417–440. doi: 10.1146/annurev.ps.41.020190.002221

Ericsson, K. A. (1999). Creative expertise as superior reproducible performance: innovative and flexible aspects of expert performance. *Psychol. Inq*. 10, 329–333.

Finke, R. A., Ward, T. B., and Smith, S. M. (1992). *Creative Cognition: Theory, Research, and Applications*. Cambridge, MA; London: The MIT Press.

Fischer, C. M., and Amabile, T. (2009). "Creativity, improvisation and organizations," in *The Routledge Companion to Creativity*, eds T. Rickards, M. A. Runco, and S. Moger (Abingdon; New York, NY: Routledge), 13–24. doi: 10.4324/9780203888841.pt2

Forgeard, M. J. C., and Kaufman, J. C. (2015). Who cares about imagination, creativity, and innovation, and why? A review. *Psychol. Aesthet. Creat. Arts* 10, 250–269. doi: 10.1037/aca0000042

Frith, S. (2012). "Creativity as a social fact," in *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance, and Perception*, eds D. J. Hargreaves, D. E. Miell, and R. A. R. MacDonald (Oxford; New York, NY: Oxford University Press), 62–72.

Furnham, A. F. (1988). *Lay Theories: Everyday Understanding of Problems in the Social Sciences*. Oxford; New York, NY; Beijing; Frankfurt; São Paulo; Sydney, NSW; Tokyo; Toronto: Pergamon Press.

Galenson, D. W. (2001). *Painting Outside the Lines: Patterns of Creativity in Modern Art*. Cambridge, MA; London: Harvard University Press.

Galenson, D. W. (2006). *Old Masters and Young Geniuses: The Two Life Cycles of Artistic Creativity*. Princeton, NJ; Oxford: Princeton University Press.

Galenson, D. W. (2009). *Conceptual Revolutions in Twentieth-Century Art*. New York, NY: Cambridge University Press. doi: 10.3386/w15073

Goldberg, L. R. (1993). The structure of phenotypic personality traits. *Am. Psychol.* 48, 26–34. doi: 10.1037/0003-066X.48.1.26

Guilford, J. P. (1968). *Intelligence, Creativity and Their Educational Implications*. San Diego, CA: Robert R. Knapp.

Hargreaves, D. J., MacDonald, R., and Miell, D. (2012). "Explaining musical imaginations: Creativity, performance, and perception," in *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance, and Perception*, eds D. J. Hargreaves, D. E. Miell, and R. A. R. MacDonald (Oxford; New York, NY: Oxford; University Press), 1–14. doi: 10.1093/acprof:oso/9780199568086.003.0001

Higgins, P. (2004). The apotheosis of Josquin Des Prez and other mythologies of musical genius. *J. Am. Musicol. Soc.* 57, 443–510. doi: 10.1525/jams.2004.57.3.443

Hill, J. (2012). "Imagining creativity: an ethnomusicological perspective on how belief systems encourage or inhibit creative activities in music," in *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance, and Perception*, eds D. J. Hargreaves, D. E. Miell, and R. A.

R. MacDonald (Oxford; New York, NY: Oxford University Press), 87–104. doi: 10.1093/acprof:oso/9780199568086.003.0006

Huovinen, E. (2011). On attributing artistic creativity. *Trópos* 2011, 65–86. doi: 10.4399/97888548471635

Huovinen, E., Tenkanen, A., and Kuusinen, V.-P. (2011). Dramaturgical and music-theoretical approaches to improvisation pedagogy. *Int. J. Music Educ.* 29, 82–100. doi: 10.1177/0255761410372761

Johnson-Laird, P. N. (2002). How jazz musicians improvise. *Music Percept.* 19, 415–442. doi: 10.1525/mp.2002.19.3.415

Jordanous, A., and Keller, B. (2012). What makes musical improvisation creative? *J. Interdisc. Music Stud.* 6, 151–175. doi: 10.4407/jims.2014.02.003

Kampylis, P., Berki, E., and Saariluoma, P. (2009). In-service and prospective teachers' conceptions of creativity. *Think. Skills Creat.* 4, 15–29. doi: 10.1016/j.tsc.2008.10.001

Katz, S. L. (2012). "The influence of the extra-musical on the composing process," in *The Act of Musical Composition: Studies in the Creative Process,* ed D. Collins (New York, NY: Ashgate), 171–185.

Katz, S. L., and Gardner, H. (2012). "Musical materials or metaphorical models? A psychological investigation of what inspires composers," in *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance, and Perception*, eds D. J. Hargreaves, D. E. Miell, and R. A. R. MacDonald (Oxford; New York, NY: Oxford University Press), 107–123. doi: 10.1093/acprof:oso/9780199568086.003.0007

Kaufman, J. C., and Glăveanu, V. P. (2019). "A review of creativity theories: what questions are we trying to answer?," in *The Cambridge Handbook of Creativity, 2nd Edn.* eds J. C. Kaufman and R. J. Sternberg (Cambridge, MA: Cambridge University Press), 27–43. doi: 10.1017/9781316979839.004

Koestler, A. (1964). *The Act of Creation: A Study of the Conscious and Unconscious Processes of Humor, Scientific Discovery and Art.* New York, NY: The Macmillan Company.

Kokotsaki, D. (2011). Student teachers' conceptions of creativity in the secondary music classroom. *Think. Skills Creat.* 6, 100–113. doi: 10.1016/j.tsc.2011.04.001

Kokotsaki, D. (2012). Pre-service student-teachers' conceptions of creativity in the primary music classroom. *Res. Stud. Music Educ.* 34, 129–156. doi: 10.1177/1321103X12466770

Konstabel, K., Lönnqvist, J.-E., Walkowitz, G., Konstabel, K., and Verkasalo, M. (2012). The 'Short Five' (S5): Measuring personality traits using comprehensive single items. *Euro. J. Pers.* 26, 13–29. doi: 10.1002/per.813

Koutsoupidou, T. (2008). Effects of different teaching styles on the development of musical creativity: insights from interviews with music specialists. *Music. Sci.* 12, 311–335. doi: 10.1177/102986490801200207

Kozbelt, A. (2012). "Process, self-evaluation and lifespan creativity trajectories in eminent composers," in *The Act of Musical Composition: Studies in the Creative Process,* ed D. Collins (Farnham: Ashgate), 27–51.

Kozbelt, A., Beghetto, R. A., and Runco, M. (2010). "Theories of creativity," in *The Cambridge Handbook of Creativity*, eds J. C. Kaufman and R. J. Sternberg (New York, NY: Cambridge University Press), 20–47. doi: 10.1017/CBO9780511763205.004

Kuhn, T. S. (1977). *The Essential Tension: Selected Studies in the Scientific Tradition and Change*. Chicago, IL; London: The University of Chicago Press. doi: 10.7208/chicago/9780226217239.001.0001

Laudan, L. (1977). *Progress and Its Problems: Towards a Theory of Scientific Growth.* Berkeley; Los Angeles, CA: University of California Press.

Lenth, R., Singmann, H., Love, J., Buerkner, P., and Herve, M. (2019). *emmeans: Estimated Marginal Means, Aka Least-Squares Means*. Available online at: https://CRAN.R-project.org/package=emmeans

Lewis, G. E. (1996). Improvisation after 1950: Afrological and Eurological perspectives. *Black Music Res. J.* 16, 91–122. doi: 10.2307/779379

Lewis, G. E., and Piekut, B. (eds.). (2016). *The Oxford Handbook of Critical Improvisation Studies, Vols. I, II*. New York, NY: Oxford University Press.

Lindauer, M. S., Orwoll, L., and Kelley, M. C. (1997). Aging artists on the creativity of their old age. *Creat. Res. J.* 10, 133–152. doi: 10.1080/10400419.1997.9651214

Linson, A., and Clarke, E. F. (2017). "Distributed cognition, ecological theory, and group improvisation," in *Distributed Creativity: Collaboration and Improvisation in Contemporary Music,* eds E. Clarke and M. Doffman (New York, NY: Oxford University Press), 52–69. doi: 10.1093/oso/9780199355914.003.0004

Littleton, K., and Mercer, N. (2012). "Communication, collaboration, and creativity: how musicians negotiate a collective "sound."," in *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance, and Perception*, eds D. J. Hargreaves, D. E. Miell, and R. A. R. MacDonald (Oxford, New York, NY: Oxford University Press), 233–241. doi: 10.1093/acprof:oso/9780199568086.003.0015

Lothwesen, K. S. (2020). The profile of music as a creative domain in people's conceptions: expanding Runco and Bahleda's 1986 study on implicit theories of creativity in a conceptual replication. *Music. Sci.* 24, 277–298. doi: 10.1177/1029864918798417

Mazzola, G., and Cherlin, P. B. (2009). *Flow, Gesture, and Spaces in Free Jazz: Towards a Theory of Collaboration*. Berlin; Heidelberg: Springer. doi: 10.1007/978-3-540-92195-0

McIntyre, P. (2006). Paul McCartney and the creation of "Yesterday": the systems model in operation. *Popul. Music* 25, 201–219. doi: 10.1017/S0261143006000936

McIntyre, P. (2008). Creativity and cultural production: a study of contemporary Western popular music songwriting. *Creat. Res. J.* 20, 40–52. doi: 10.1080/10400410701841898

Mullet, D. R., Willerson, A., Lamb, K. N., and Kettler, T. (2016). Examining teacher perceptions of creativity: a systematic review of the literature. *Think. Skills Creat.* 21, 9–30. doi: 10.1016/j.tsc.2016.05.001

Nelson, C. (2015). "Discourses of creativity," in *The Routledge Handbook of Language and Creativity,* ed R. H. Jones (London; New York, NY: Routledge), 170–187.

Nelson, C. (2018). Beyond Prometheus: creativity, discourse, ideology, and the anthropocene. *Knowl. Cult.* 6, 111–131. doi: 10.22381/KC6220188

Nettl, B. (1974). Thoughts on improvisation: a comparative approach. *Music. Q.* 60, 1–19. doi: 10.1093/mq/LX.1.1

Nettl, B., and Riddle, R. (1998). "Taqsim Nahawand revisited: the musicianship of Jihad Racy," in *In the Course of Performance: Studies in the World of Musical Improvisation*, eds B. Nettl and M. Russell (Chicago, IL; London: The University of Chicago Press), 369–393.

Nettl, B., and Russell, M. (1998). *In the Course of Performance: Studies in the World of Musical Improvisation*. Chicago, IL; London: The University of Chicago Press.

Nettle, D. (2001). *Strong Imagination: Madness, Creativity and Human Nature*. New York, NY: Oxford University Press.

Odena, O., and Welch, G. (2009). A generative model of teachers' thinking on musical creativity. *Psychol. Music* 37, 416–442. doi: 10.1177/0305735608100374

Odena, O., and Welch, G. (2012). "Teachers' perceptions of creativity," in *Musical Creativity: Insights from Music Education Research*, ed O. Odena (Farnham; Burlington, VT: Ashgate), 29–48.

Patston, T. J., Cropley, D. H., Marrone, R. L., and Kaufman, J. C. (2018). Teacher implicit beliefs of creativity: is there an arts bias? *Teach. Teach. Educ.* 75, 366–374. doi: 10.1016/j.tate.2018.08.001

Pavlović, J., and Maksić, S. (2019). Implicit theories of creativity in higher education: a constructivist study. *J. Constr. Psychol.* 32, 254–273. doi: 10.1080/10720537.2018.1477639

Plucker, J. A., Beghetto, R. A., and Dow, G. T. (2004). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educ. Psychol.* 39, 83–96. doi: 10.1207/s15326985ep3902_1

Pressing, J. (1988). "Improvisation: methods and models," in *Generative Processes in Music: The Psychology of Performance, Improvisation, and Composition,* ed J. A. Sloboda (Oxford: Clarendon Press), 129–178. doi: 10.1093/acprof:oso/9780198508465.003.0007

Pressing, J. (1998). "Psychological constraints on improvisational expertise and communication," in *In the Course of Performance: Studies in the World of Musical Improvisation*, eds B. Nettl and M. Russell (Chicago, IL; London: The University of Chicago Press), 47–67.

Prévost, E. (2004). "The discourse of a dysfunctional drummer: collaborative dissonances, improvisation, and cultural theory," in *The Other Side of Nowhere:*

Jazz, Improvisation, and Communities in Dialogue, eds D. Fischlin and A. Heble (Middletown, CT: Wesleyan University Press), 353–366.

QSR International Pty Ltd (2018). *NVivo (Version 12.6.0)*. Available online at: https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

R Core Team (2019). *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing. Available online at: https://www.R-project.org/

Revelle, W. (2019). *psych: Procedures for Psychological, Psychometric, and Personality Research*. R package version 1.9.12. Northwestern University. Available online at: https://CRAN.R-project.org/package=psych

Runco, M. (2007). *Creativity: Theories and Themes: Research*, *Development, and Practice*. Burlington, MA: Academic Press.

Runco, M. A., and Johnson, D. J. (2002). Parents' and teachers' implicit theories of children's creativity: a cross-cultural perspective. *Creat. Res. J.* 14, 427–438. doi: 10.1207/S15326934CRJ1434_12

Runco, M. A., Johnson, D. J., and Bear, P. K. (1993). Parents' and teachers' implicit theories of children's creativity. *Child Stud. J.* 23, 91–113.

Saint-Germier, P., and Canonne, C. (2020). Coordinating free improvisation: an integrative framework for the study of collective improvisation. *Music. Sci.* 1–21. doi: 10.1177/1029864920976182

Sampson, V., and Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: current perspectives and recommendations for future directions. *Sci. Educ*. 92, 447–472. doi: 10.1002/sce.20276

Sawyer, R. K. (2003). *Group Creativity: Music*, *Theater, Collaboration*. New York, NY; London: Routledge.

Schiavio, A., Moran, N., van der Schyff, D., Biasutti, M., and Parncutt, R. (2020). Processes and experiences of creative cognition in seven Western classical composers. *Music. Sci.* 1–23. doi: 10.1177/1029864920 943931

Schuiling, F. (2019). *The Instant Composers Pool and Improvisation Beyond Jazz*. New York, NY; London: Routledge. doi: 10.4324/9781351254380

Simonton, D. K. (1997). Creative productivity: a predictive and explanatory model of career trajectories and landmarks. *Psychol. Rev*. 104, 66–89. doi: 10.1037/0033-295X.104.1.66

Simonton, D. K. (1999). Creativity as blind variation and selective retention: is the creative process Darwinian? *Psychol. Inq*. 10, 309–328.

Simonton, D. K. (2010). Creative thought as blind-variation and selective-retention: combinatorial models of exceptional creativity. *Phys. Life Rev*. 7, 156–179. doi: 10.1016/j.plrev.2010.02.002

Simonton, D. K. (2015). On praising convergent thinking: creativity as blind variation and selective retention. *Creat. Res. J.* 27, 262–270. doi: 10.1080/10400419.2015.1063877

Slominski, T. (2020). "Fielding the field: belonging, disciplinarity, and queer scholarly lives," in *Queering the Field: Sounding Out in Ethnomusicology,* eds G. Barz and W. Cheng (New York, NY: Oxford University Press), 217–232.

Solis, G., and Nettl, B. (eds.). (2009). *Musical Improvisation: Art*, *Education, and Society*. Urbana; Chicago, IL: University of Illinois Press.

Spiel, C., and von Korff, C. (1998). Implicit theories of creativity: the conceptions of politicians, scientists, artists and school teachers. *High Abil. Stud.* 9, 43–58. doi: 10.1080/1359813980090104

Sternberg, R. J. (1985). Implicit theories of intelligence, creativity, and wisdom. *J. Pers. Soc. Psychol.* 49, 607–627. doi: 10.1037/0022-3514.49.3.607

Sternberg, R. J. (2012). The assessment of creativity: an investment-based approach. *Creat. Res. J*. 24, 3–12. doi: 10.1080/10400419.2012.652925

Sternberg, R. J. (2018). A triangular theory of creativity. *Psychol. Aesthet. Creat. Arts* 12, 50–67. doi: 10.1037/aca0000095

Sternberg, R. J., and Lubart, T. I. (1991). An investment theory of creativity and its development. *Hum. Dev*. 34, 1–31. doi: 10.1159/000277029

Stockhausen, K. (1964). "Komposition 1956 Nr. 2," in *Texte zu eigenen Werken, zur Kunst Anderer, Aktuelles, Band II*, ed K. Stockhausen (Cologne: Verlag M. DuMont Schauberg), 23–36.

Straus, J. N. (1990). *Remaking the Past: Musical Modernism and the Influence of the Tonal Tradition*. Cambridge: Harvard University Press.

Tafuri, J. (2006). "Processes and teaching strategies in musical improvisation with children," in *Musical Creativity: Multidisciplinary Research in Theory and Practice,* eds I. Deliège and G. A. Wiggins (Hove; New York, NY: Psychology Press), 134–157.

Toulmin, S. E. (1958). *The Uses of Argument*. London; New York, NY: Cambridge University Press.

Turino, T. (2009). "Formulas and improvisation in participatory music," in *Musical Improvisation: Art, Education, and Society*, eds G. Solis and B. Nettl (Urbana; Chicago, IL: University of Illinois Press), 103–116.

van der Schyff, D., Schiavio, A., Walton, A., Velardo, V., and Chemero, A. (2018). Musical creativity and the embodied mind: exploring the possibilities of 4E cognition and dynamical systems theory. *Music Sci*. 1, 1–18. doi: 10.1177/2059204318792319

Wallas, G. (1926). *The Art of Thought*. London: Jonathan Cape.

Webster, P. R. (1990). Creativity as creative thinking. *Music Educ. J.* 76, 22–28. doi: 10.2307/3401073

Wiggins, G. A. (2012). "Defining inspiration? Modelling the non-conscious creative process," in *The Act of Musical Composition: Studies in the Creative Process,* ed D. Collins (Farnham: Ashgate), 233–253.

Williamon, A., Thompson, S., Lisboa, T., and Wiffen, C. (2006). "Creativity, originality, and value in music performance," in *Musical Creativity: Multidisciplinary Research in Theory and Practice,* eds I. Deliège and G. A. Wiggins (Hove; New York, NY: Psychology Press), 161–180.

Winemiller, J. T. (1997). Recontextualizing Handel's borrowing. *J. Musicol.* 15, 444–470. doi: 10.2307/764003

Winther, R. G. (2015). *The Structure of Scientific Theories*. Stanford Encyclopedia of Philosophy. Available online at: https://plato.stanford.edu/entries/structure-scientific-theories/#SynVie

Xenakis, I. (1990). Sieves. *Perspect. New Music* 28, 58–78. doi: 10.2307/833343

Young, M., and Blackwell, T. (2016). "Live algorithms for music: can computers be improvisers?," in *The Oxford Handbook of Critical Improvisation Studies, Vol. II,* eds G. E. Lewis and B. Piekut (New York, NY: Oxford University Press), 507–528.

Yudkin, J. (1992). Beethoven's "Mozart" quartet. *J. Am. Musicol. Soc.* 45, 30–74. doi: 10.2307/831489

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The Role of the Mirror System in Influencing Musicians' Evaluation of Musical Creativity: A tDCS Study

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Evidence reported in the literature suggests that the mirror system not only plays a role in recognizing motor action but also fosters a better understanding of other people because it helps an individual assume another's perspective. This led to the idea, supported by research findings, that people with higher empathy scores should show higher activation of the mirror system. Recently, it has been hypothesized that a purely auditory mirror system exists. In this study, we aimed to explore the possibility that this system might play a particular role for musicians. Specifically, this system would impact their response to a new piece of music by using non-invasive brain stimulation to modulate the activation of the mirror system. A sample of 40 young musicians was involved in this study. Half of the participants were randomly assigned to a cathodal stimulation condition, while the other half was used as a control. After listening to a new piece of music, participants were asked to rate the creativity of the piece (by focusing on how interesting, innovative, and exciting the piece was) as well as their general emotional response to it. Their empathy levels were also assessed using the Interpersonal Reactivity Index (IRI). Results showed that the cathodal stimulation of the mirror system negatively affected both the perception of creativity (level of innovation) and the emotional response to the music. There was no significant difference in the ratings of how interesting the piece was perceived. The effect was mediated by the individuals' level of empathy. Specifically, empathic concern and fantasy dimensions increased the evaluation of creativity. Results also showed that participants reported less emotion with a negative valence in the cathodal stimulation condition.

Keywords: mirror system, auditory mirror system, creativity, musicians, empathy, tDCS, left ventral premotor cortex, emotions

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INTRODUCTION

Theoretical Background on the Mirror Neuron System

The mirror neuron system (MNS) has had a large impact on the psychological community since the discovery of mirror neurons in the ventral premotor (F5) area of Macaque monkeys in 1992. Mirror neurons have become widely investigated due to their unique nature (Cattaneo and Rizzolatti, 2009; Kilner and Lemon, 2013; Jeon and Lee, 2018). Mirror neurons diverge from motor and sensory neurons due to the fact that they become active both with the performance of an action and with the observation of another performing the action (Rizzolatti, 2005; Kilner and Lemon, 2013).

Since the MNS was discovered, research on the MNS has branched out from studying the response to simple motor actions. An interesting discovery is the fact that the auditory system is also involved. To be more specific, a group of audiovisual neurons in the ventral premotor F5 area seems to be able to discriminate between different actions with about 90% accuracy when only seen or only heard (Kohler et al., 2002; Keysers et al., 2003). Further research on humans supports the fact that there are auditory mirror neurons that activate in response to the sounds of actions we are capable of performing (Gazzola et al., 2006). This makes sense when reflecting on the fact that the representation of sensory and motor information in the brain seems to be integrated at many levels: For this reason, seeing or hearing action-related stimuli may automatically cue the movements required to respond to or produce them, in order to guide perception of musical stimuli (Stephan et al., 2018). This line of research has led to interesting discoveries, including the role that the MNS might play, in humans, in facilitating or mediating the understanding of music (Jiang et al., 2019).

Focusing more specifically on response to music in musicians, Lahav et al. (2007) found that auditory mirror activation only occurred when listening to a passage from a song that participants were taught to play on the piano. This did not occur when listening to a passage of an unfamiliar song. This suggests that only sounds within our motor repertoire will activate the auditory MNS. The researchers speculated that participants may not have responded to songs they had not been taught, due to their unfamiliarity with the instrument and music in general (Lahav et al., 2007). A similar study by Bangert et al. (2006) suggested that professional musicians have a greater understanding of the motor and auditory parts of piano playing, allowing them to still have significant understanding of the piano without either motor or auditory stimuli and supporting the idea that professional musicians would show more MNS activity with new music than would non-professionals. More data also support the fact that mirror neuron activation is modulated by musical expertise and that MNS activation in musicians may stem from imagining themselves playing the piece, so it is most likely stronger when they listen to music performed on their main instrument (Hou et al., 2017).

Evidence from recent studies that focus on the MNS (Ramachandra et al., 2009) suggests that the MNS may serve as a common neural substrate for processing not only motor information but also emotional and other higher-level cognitive information. Researchers (Warren et al., 2006; Banissy et al., 2010) explored the possible role of the auditory MNS in engaging different emotional systems as well as helping to discriminate auditory emotions, highlighting how distinct functional subsystems within the auditory–motor mirror network respond preferentially to emotional valence and arousal properties of heard vocalizations. To be more specific, Warren et al. (2006) reported that listening to non-verbal vocalizations can trigger an automatic preparation of responsive gestures, an effect that is greatest for positive-valence and high-arousal emotions. Yet the specific role played by this system when professional musicians listen to music where their main instrument is played has not been explored yet, to our knowledge.

The Present Study: The Relationship Among Creativity, Empathy, and the MNS

The present study aimed to explore, at a preliminary level, if and how altering the activation of the MNS affects either the emotion response to music or the evaluation of musical creativity by professional musicians.

The added focus on creativity is derived from two lines of research. The first one highlights the relationships between creativity and empathy (and hence creativity and the MNS) and the second one the relationships among creativity, music, and empathy. The first relationship starts from the idea that creativity is linked to and supported by social aspects (Glaveanu et al., 2013), implying that a creative person will benefit from being connected to other people's minds and feelings (Form and Kaernbach, 2018), aspects that are also promoted by the activation of the MNS. This view is supported by the empirical evidence showing that creative activity can be used as a tool to directly promote empathy and indirectly promote other social–emotional skills (Morizio, 2021). For example, painting in a virtual-reality environment has been reported to promote both creativity and empathy (Gerry, 2017), and creative dance has been used effectively to enhance the link between creativity, social interaction, and the MNS (Batson, 2013). The second line of research, starting from the idea that music can be seen as a specific type of creative thinking (Antonietti and Colombo, 2014), suggests that empathy influences the appreciation of performing and creative arts, including music (Wöllner, 2012). This could be linked to the fact that the performance of music, as it is true of creative activities, as discussed above, is claimed to be a social activity, and hence, even just listening to music has been shown to involve empathy (Cross et al., 2012; Wöllner, 2012; Balteş and Miu, 2014; Sittler et al., 2019). To be more specific, Kawakami and Katahira (2015) reported that fantasy and perspective taking, two sub-components of trait empathy assessed by the Interpersonal Reactivity Index (IRI) questionnaire, are correlated with the emotional response to sad music. Following this line of reasoning, empathy emerges as a variable that impacts the mirror system, as also discussed in a recent meta-analysis (Bekkali et al., 2020). Research highlights that individuals who showed high motor and facial mimicry more frequently had higher empathy scores (Sonnby-Borgström et al., 2003). Moreover, neuroimaging studies show positive correlations between the activation of the MNS and empathy scores from the IRI (Baird et al., 2011). These studies included both auditory and visual paradigms, suggesting that empathy could possibly play a part in both functions of the MNS. However, Baird et al. (2011) speculated that the brain regions associated with empathy could be related to partially different brain networks, depending on the specific form of empathy investigated (e.g., motor, emotional, and cognitive empathy), and hence, more studies that focus more specifically on specific forms of empathy are needed. They also explain that mirror neurons account for only a minority of cells in the brain regions associated with the MNS but that activation in the corresponding areas in humans has been heavily attributed to mirror neurons, prompting further clarification and study (Baird et al., 2011). Possible involvement of the MNS was also reported by Schnell et al. (2011), who found that cognitive empathy involves references to an individual's own affective state. Our own affective state impacts how we understand the affective state of others. This way of referencing ourselves to understand others is similar to how we reference our own motor repertoire in order to understand the sound produced by another (Gazzola et al., 2006; Lahav et al., 2007). Gazzola et al. (2006) showed that participants who scored higher on a perspective-taking empathy scale showed stronger activation of the mirror system with data supporting that it was not due to lack of attention. This evidence suggests that empathy could play a role in the MNS but is not enough to declare a definitive relationship.

Aims and Hypotheses of the Study

Starting from these premises, in this study we investigated if the auditory MNS might act in a specific way upon professional musicians. To do so, we used transcranial direct current stimulation (tDCS) to inhibit the activation of the MNS. Based on the research discussed above, we investigated how professional musicians would respond (both emotionally and cognitively) to a new piece of music involving the instrument they play. To be more specific, we investigated how cathodal tDCS stimulation of a musicians' brain area associated with the MNS would affect their judgment of how creative the music was as well as their emotional response to it. Empathy has also been shown to have a relationship with the MNS, although the exact nature of this relationship has not been established yet (Gazzola et al., 2006; Baird et al., 2011; Schnell et al., 2011). Therefore, it was added as a covariate using the IRI (which has been used in the research mentioned above that focused on the relationship between music and empathy) in order to identify any possible moderating effects.

We expected that participants who received cathodal tDCS would rate the music as less creative when compared to participants in the sham condition, given the fact that their auditory MNS would be impaired. We also expected cathodal tDCS to impact self-reported emotional reaction to music, by way of reducing the intensity of reported emotions. This hypothesis is linked to the literature discussed above, which highlights the possible role of the MNS in processing emotional information. Since this specific processing seems (as noted above) linked specifically to the emotional valence and arousal/control associated with specific pieces of music, in this study we decided to assess these aspects by using the Geneva Emotion Wheel (GEW) (see details below), which focuses on assessing individual emotional responses on these two axes. Finally, given the relationships between creativity, empathy, and music, we expected individual levels of empathy to be positively associated with creativity ratings and to play the role of significant mediators between our two main variables (tDCS and evaluation of creativity).

MATERIALS AND METHODS

The study has been reviewed and approved by the Champlain College Institutional Review Board (IRB) (IRB protocol number: IRB000143).

Sample

Forty young musicians (age range: 18–22, mean = 19.80; SD = 1.56; $F = 15$) joined the study and were randomly assigned either to the experimental group (cathodal stimulation) or to the control group (sham stimulation).

Participants were screened before being invited to join the experiment by checking that their principal instrument would be either the piano, violin, or cello (the instruments played in the piece of music used during our experiment; see below for details). We also verified that they would practice a minimum of 4 h/day and have performed in public in a professional setting at least five times. Of the recruited participants, 16 were pianists, 14 were violinists, and 10 were cellists.

Apparatus

tDCS Equipment

In this study, we used 1300A 1 × 1 Transcranial Direct Current Low-Intensity Stimulator by Soterix Medical to deliver brain stimulation to our participants. We used two 5 × 5 cm rubber electrodes enveloped in saline-soaked sponges covered with conductive gel. For the experimental conditions (cathodal), the stimulation was set at 1.5 mA (current density: 0.02857 mA/cm^2) for 20 min. In the control (sham) condition, the equipment started the stimulation normally and ramped up to the target intensity of 1.5 mA; it decreased to 0 mA after 5 s. This gave participants the impression of actually receiving stimulation, when in reality the stimulation lasted only 5 s, thus having no actual effect on brain functions.

For the experimental condition, the electrodes were placed on the left ventral premotor cortex using the 10–20 system (F5 location). The anodal electrode was placed on the upper right forearm. The same montage was used for the sham condition.

GEW

The GEW (Scherer, 2005; Scherer et al., 2013) measures emotional reactions to objects, events, and situations. Participants were asked to indicate the emotion(s) they experienced by choosing intensities for a single emotion or a blend of several emotions out of 20 different options. The emotions are arranged in a wheel shape with the axes being defined by two major dimensions of emotional experience: high vs. low control and positive vs. negative valence. Five degrees of intensity are being proposed, represented by circles of different sizes. In addition, "None" (no emotion felt) and "Other" (different emotion felt) options are provided. The GEW has been used to assess affect and emotional responses in many different research designs, as critically discussed in a GEW rating study (Sacharin et al., 2012). Results from these studies support the validity of the GEW. Other studies reported that participants tend to prefer the GEW over alternative measures (Desmet et al., 2000) and to judge the GEW as clear to understand and useful in differentiating between emotions (Caicedo and Van Beuzekom, 2006). The GEW has also been used specifically to assess emotional responses to music in neuropsychological experiments (Dutta et al., 2020).

Creativity Evaluation

We asked participants to rate specific factors that have been reported in the literature to be associated with creativity: interest (Fürst and Grin, 2018; Li et al., 2018; Moreira et al., 2020), innovation (Acar et al., 2017; Rietzschel and Ritter, 2018; Lee et al., 2020), and excitement (Paulus and Nijstad, 2019; Fink et al., 2020). Participants were asked to rate the creativity of the musical piece by rating how interesting, innovative, and exiting the piece was on a 9-point Likert scale. To be more specific, participants were told: "You are now asked to evaluate the creativity of the piece you just listened to. How interesting/innovating/exciting you think it is?"

IRI

The IRI (Davis, 1980, 1983) is a multidimensional measure of dispositional empathy that is widely used to assess empathy and has a strong validity portfolio (Keaton, 2017). It is a self-report questionnaire, which includes 28 items answered on a 5-point Likert scale ranging from "Does not describe me well" to "Describes me very well." It consists of four subscales: perspective taking (PT, the tendency to spontaneously adopt the psychological point of view of others in everyday life); empathic concern (EC, the tendency to experience feelings of sympathy and compassion for unfortunate others); personal distress (PD, the tendency to experience distress and discomfort in response to extreme distress in others); and fantasy (FS, the tendency to imaginatively transpose oneself into fictional situations). The relationships among subscales have been statistically tested by analyzing the validity of a hierarchical structure of the IRI (Pulos et al., 2004).

Music

Dreaming Cities is a five-movement piano trio (violin, cello, and piano) by Damon Ferrante. In this experiment, participants listened to the third movement. The third movement is a slow movement whose material is a variation of the musical theme that occurs at the beginning of the work. The third movement's sparce, lyrical texture highlights the characteristic musical voices of each instrument. It was not written with a specific emotional tone in mind, but, rather, focusing on the slow, melodic interplay of the instruments. This piece of music was not familiar to any participant (a familiarity check was performed at the end of the experiment).

Procedure

After reading and signing the consent form and before starting the experimental procedure, participants were asked by researchers for any questions they might have.

The consent form included information about the tDCS equipment and possible side effects, listed exclusion criteria [e.g., personal or family history of seizures, traumatic brain injury (TBI) in the previous year, pregnancy, or any metallic implants in the skull], described the experiment and the different tasks, and reminded the participants that they would be free to leave the experiment at any time and to ask for their data to be deleted. We also explained how we were going to guarantee participants' confidentiality by only using anonymous codes to identify the records.

After placing the electrodes and starting the tDCS stimulation (either actual stimulation or sham) and waiting 60 s to be sure that the equipment was functioning properly and no side effects were reported, participants were instructed to close and relax for 5 min to wait for the tDCS to have an effect. After that, participants were asked to open their eyes and listen to the piece of music selected for our experiment.

When the music was over, participants were asked to fill out the GEW, the creativity evaluation, and the IRI.

After that, the electrodes were taken off. Participants were asked if they had any questions, debriefed, and thanked for their participation.

RESULTS

Effects of Brain Stimulation on Emotional Response and Creative Evaluation

To explore the effects of the brain stimulation on emotional reaction as well as creative evaluation of the musical piece, we ran a general linear model (GLM) multivariate analysis of variance (MANOVA), using the condition as an independent variable and the three creative evaluation scales (interest, innovation, and excitement) and self-report of emotional response (categorized into two variables: sum of positive valence emotions and sum of negative valence emotions) as dependent variables. We added the IRI subscales as covariates to control for their effect.

Mean scores and standard deviations are reported in **Table 1**.

The test of between-subject effects returned a significant main effect of stimulation condition on the evaluation of the creativity of the piece. Two of the considered dimensions were significantly affected: how innovative the piece was ($F_{1,34} = 45.76$, $p < 0.001$, $\eta^2 = 0.57$) and how exciting ($F_{1,34} = 53.73$, $p < 0.001$, $\eta^2 = 0.61$). In both cases, cathodal stimulation decreased the reported perception of creativity.

The IRI subscales also had a significant effect on most of the considered dimensions. To be more specific, the score on the PT subscale affected how participants rated the piece to be interesting ($F_{1,34} = 13.04$, $p = 0.001$, $\eta^2 = 0.28$), innovative ($F_{1,34} = 37.70$, $p < 0.001$, $\eta^2 = 0.53$), and exciting ($F_{1,34} = 31.88$, $p < 0.001$, $\eta^2 = 0.48$). The score on the FS subscale significantly affected

TABLE 1 | Mean scores and standard deviation for self-report evaluation of creativity and emotional response.

Self-report	Condition	Mean	Standard deviation
Creativity—Interesting	sham	6.20	1.88
	cathodal	6.40	1.39
Creativity—Innovative	sham	5.20	2.42
	cathodal	4.90	2.22
Creativity—Exciting	sham	4.40	2.30
	cathodal	4.00	2.15
Emotions—Positive Valence	sham	31.05	10.32
	cathodal	31.95	9.98
Emotions—Negative Valence	sham	10.35	4.70
	cathodal	4.15	1.81

the rating for innovation ($F_{1,34}$ = 14.70, p = 0.001, η^2 = 0.30) and excitement ($F_{1,34}$ = 17.81, p < 0.001, η^2 = 0.34). The EC subscale scores affected how interesting ($F_{1,34}$ = 16.93, p < 0.001, η^2 = 0.33), innovative ($F_{1,34}$ = 8.84, p = 0.005, η^2 = 0.21), and exciting ($F_{1,34}$ = 14.75, p = 0.001, η^2 = 0.30) the piece was perceived by participants, and the same was true for the PD scale: interesting ($F_{1,34}$ = 41.92, p < 0.001, η^2 = 0.55), innovative ($F_{1,34}$ = 94.16, p < 0.001, η^2 = 0.73), and exciting ($F_{1,34}$ = 60.01, p < 0.001, η^2 = 0.64).

Focusing on the self-report emotional response to the piece, cathodal stimulation significantly affected emotions with negative valence ($F_{1,34}$ = 17.93, p < 0.001, η^2 = 0.34). Cathodal stimulation decreased the intensity of negative emotions reported by participants.

All the IRI subscales other than FS affected the rating of emotions with negative valence: PT ($F_{1,34}$ = 15.96, p < 0.001, η^2 = 0.32), EC ($F_{1,34}$ = 11.02, p = 0.002, η^2 = 0.24), and PD ($F_{1,34}$ = 24.41, p < 0.001, η^2 = 0.42).

Mediation Effect of Empathy

Since in the previous analyses the IRI subscales had a significant effect as covariates, we ran further analyses to explore in more detail the possible mediation effects that these subscales had on our main variables.

Using the software JAMOVI 1.2.3, we ran a GLM mediation model using as dependent variables (one for each model) those that had significant results in the previous analyses (i.e., evaluation of how innovative the piece was, evaluation of how exciting the piece was, and self-report of emotions with negative valence), the tDCS condition as independent variable, and the IRI subscales as mediators.

The first model analyzed the effect of our independent variable (tDCS condition) on the evaluation of the creativity of the music based on how innovative it was, taking into account the role of the IRI empathy subscales as mediators. The full model is reported in **Figure 1**.

As can be derived from the indirect effects reported in **Figure 1**, the FS and EC subscales appeared to be the ones who significantly mediated the effect of tDCS, by increasing the level of creative evaluation (focus on innovation).

The second model analyzed the effect of our independent variable (tDCS condition) on the evaluation of the creativity of the music based on how exciting it was, considering the role of the IRI empathy subscales as moderators. The full model is reported in **Figure 2**. As can be seen from the indirect effects reported in **Figure 2**, the same two mediators (the FS and EC subscales) had a significant effect on the evaluation of creativity (focus on excitement), by increasing the level of creative evaluation.

The last model analyzed the effect of our independent variable (tDCS condition) on the self-reported evaluation of emotions (negative valence), considering the role of the IRI empathy subscales as mediators. The full model is reported in **Figure 3**. In this case, the subscale EC appeared to have a significant effect, by decreasing the intensity of emotions with negative valence reported by participants.

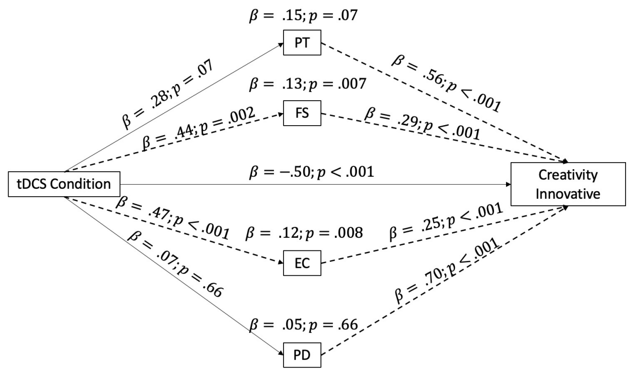

FIGURE 1 | Mediation model taking into consideration the IRI subscales as mediators of the relationship between the tDCS condition and the evaluation of creativity/innovation. The arrow indicates the direction of the mediation, and the dotted lines highlight significant mediation effects. IRI subscales: PT, perspective taking; FS, fantasy; EC, empathic concern; PD, personal distress.

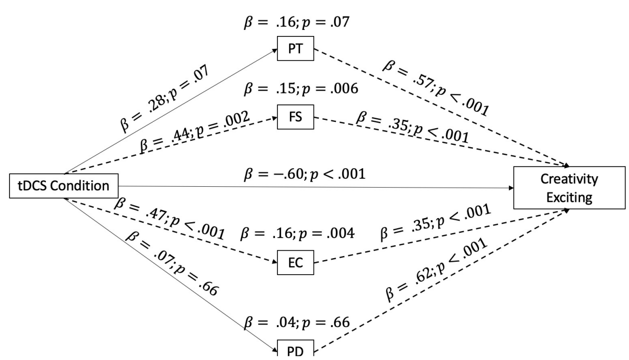

FIGURE 2 | Mediation model taking into consideration the IRI subscales as mediators of the relationship between the tDCS condition and the evaluation of creativity/excitement. The arrow indicates the direction of the mediation, and the dotted lines highlight significant mediation effects. IRI subscales: PT, perspective taking; FS, fantasy; EC empathic concern; PD personal distress.

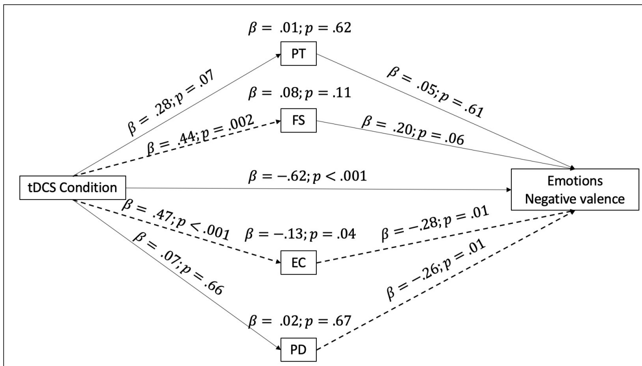

FIGURE 3 | Mediation model taking into consideration the IRI subscales as mediators of the relationship between the tDCS condition and the self-report of emotions (negative valence). The arrow indicates the direction of the mediation, and the dotted lines highlight significant mediation effects. IRI subscales: PT, perspective taking; FS, fantasy; EC, empathic concern; PD, personal distress.

DISCUSSION AND CONCLUSION

The present study aimed at investigating the role of the auditory mirror system in influencing the evaluation of creativity as well as the emotional reactions of professional musicians while listening to a new piece of music.

Our first hypothesis focused on the effect of cathodal stimulation in reducing the perceived creativity of the new piece of music. This hypothesis was guided by the fact that evidence from literature supports the idea that the auditory MNS plays a role in musicians' response to music (Bangert et al., 2006; Lahav et al., 2007) and also that the MNS's role is linked to processing not only motor information but also emotional and other higher-level cognitive information, like creativity (Ramachandra et al., 2009). Moreover, empathy has been reported to influence the evaluation of creativity levels of performing arts, including music (Wöllner, 2012), and the MNS is involved in empathic responses (Gazzola et al., 2006; Baird et al., 2011; Schnell et al., 2011). For these reasons, we believed that modulating the activation of musicians' MNS would have led to differences in their evaluation of the creativity level of a new piece of music. Our results partially confirmed this hypothesis. Participants who underwent cathodal stimulation rated the piece as less innovative and exciting when compared to participants in the sham condition. On the other hand, their evaluation of the level of interest was not significantly affected by the stimulation. Our data seem to confirm a role of the MNS in evaluating the creativity of a music piece, but the role seems to be rather specific. Both the cognitive evaluation of the creative process (the innovation of the piece) and the emotional reaction to it (excitement) appear to be influenced by the activation of the MNS. When the activation is disrupted (lowered by cathodal stimulation), the piece is perceived as less innovative and less exciting. On the other end, how interesting the piece is appears to be examined through a different circuit. We might hypothesize that this evaluation can be related to individual differences, hence not being directly affected by the modulation of the MNS. This reading is supported by research data stating that music preference is significantly influenced by a combination of the individuals' perception of the cognitive, emotional, and cultural functions of music, together with physiological arousal and familiarity (Schäfer and Sedlmeier, 2010). Further research might include evaluation of these variables into a tDCS design similar to the one presented in this study to better assess their specific role. A possible reading of the non-significant results concerning how interesting the piece was is related to the type of assessment used in this study. It has been reported that interest is directly linked to participants' level of attention (Peters et al., 2005; Li et al., 2020), something that we did not control for in our study. This aspect should be taken into consideration in future studies.

The above-mentioned results regarding the effect of brain stimulation on the evaluation of how exciting a music piece is stresses a conceptual link with our second hypothesis, which focuses on the effect of tDCS on participants' reported emotions after listening to the music. This hypothesis was formulated based on the evidence (Warren et al., 2006; Banissy et al., 2010) that the auditory MNS plays a significant role in responding to auditory stimuli with emotional valance. Our hypothesis was partially confirmed. To be more precise, it was confirmed only for emotion with a negative valence (after cathodal stimulation, people reported less emotion with a negative valence) but not for emotions with positive valence. There are two possible explanations for this result. The first one refers to the specific music we were using for our study. Even if the movement that we used was not written with a specific emotional tone, it has a slow tempo, and it is mainly written in the tonality of D minor. Minor keys and lower tempos tend to be associated with more negative emotions like sadness (Webster and Weir, 2005), so the effect of neuromodulation might have been more pronounced for these specific emotions. Also, fMRI data suggest that familiarity seems to play an important role in making the listeners emotionally engaged with music (Pereira et al., 2011), and our piece was unfamiliar to all our participants. Future studies should add a familiar piece as a comparison, to understand if increased familiarity might lead to a different result.

Our last hypothesis was linked to the possible mediating effect of individual empathy levels, inspired by the fact that studies show positive correlations between the activation of the MNS and empathy scores from the IRI (Baird et al., 2011). Results from our mediation models supported this hypothesis and highlighted the specific role of different empathy traits. Two IRI subscales appeared to mediate the effect of brain stimulation by increasing the evaluation of creativity, even after cathodal stimulation: EC (tendency to experience feelings of sympathy and compassion for unfortunate others) and FS (tendency to imaginatively transpose oneself into fictional situations). Previous studies reported similar findings when focusing only on the role of trait empathy in music appreciation. For example, Garrido and Schubert (2011) reported a significant correlation between EC scores and liking sad music. In another study (Vuoskoski et al., 2011), a similar positive correlation between the same subscales that were reported as significant moderators in our study (EC and FS) and music appreciation was found. A similar result emerged when focusing on the mediating effect of trait empathy on perceived emotions, with a significant moderating role of EC emerging but only for negative-valence emotions. Altogether, results from the mediation models seem to imply that specific empathic traits might help the listener enjoy music that is perceived as sad by increasing daydreaming about a fictional world dominated by the emotional valence elicited by the music and experience compassion inspired by the feelings suggested by the music. Future studies should test this reading by adding a measure of visual imagery experiences to the research design and testing the same design with a music written in a major key and with a faster tempo.

Conclusion

The present study presents some interesting, if preliminary, data on the role of the auditory MNS in mediating the cognitive and emotional response to music of professional musicians. In particular, we were able to highlight a role of the auditory MNS in evaluating specific aspects of musical creativity (innovation and excitement) and in influencing, at least partially, the emotional response to the same music. Moreover, we were able to highlight the specific mediating role of trait empathy. From a theoretical standpoint, our results offer more evidence to better clarify the role of the auditory MNS in evaluating music, as well as highlighting some more insights into the specific role of the subcomponents of empathy in mediating the cognitive and affective responses of the MNS—something that, as highlighted in our literature review, is still in need of additional clarification (Baird et al., 2011).

From an applied standpoint, the results offer some interesting implications for the use of music to promote creativity as well as social skill in different educational settings. The relationship between creativity and empathy within the response to music could be used to support specific programs aimed at working with youths with autism spectrum disorders (Forti et al., 2020) but could also be used to inform assessment in music composition (Deutsch, 2016).

These results are promising and worth being further explored by future studies. Yet some additional limitations should be highlighted. Our study did not explore the effect of anodal stimulation and focused only on the evaluation of one piece of music, which was perceived by participants as sad because of the specific tempo and key. Future studies should explore the effects of anodal stimulation, as well as add information about the effects of the auditory MNS in mediating the creative evaluation and emotional response to music that is perceived as happy. Moreover, we worked with a sample of professional but young musicians. Future studies should involve older musicians to test if expertise might play an additional moderation role. Finally, even if we achieved a good effect size (as can been derived by the η^2 values), we have been working with a relatively small sample. Future studies should aim at collecting data from a larger sample.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Champlain College IRB. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BC designed the study, collected data, run analyses, and wrote the manuscript. RA designed the study and wrote the manuscript. SB analyzed the data and wrote the manuscript. FB designed the methodology and wrote the manuscript. AA designed the study and supervised the study. All authors contributed to the article and approved the submitted version.

REFERENCES

Acar, S., Burnett, C., and Cabra, J. F. (2017). Ingredients of creativity: originality and more. *Creat. Res. J.* 29, 133–144. doi: 10.1080/10400419.2017.1302776

Antonietti, A., and Colombo, B. (2014). "Musical thinking as a kind of creative thinking," in *Creativity Research: An Inter-Disciplinary and Multi-Disciplinary Research Handbook*, ed. E. Shiu (London: Routledge), 233–246.

Baird, A. D., Scheffer, I. E., and Wilson, S. J. (2011). Mirror neuron system involvement in empathy: a critical look at the evidence. *Soc. Neurosci.* 6, 327–335. doi: 10.1080/17470919.2010.547085

Balteş, F. R., and Miu, A. C. (2014). Emotions during live music performance: links with individual differences in empathy, visual imagery, and mood. *Psychomusicology* 24:58. doi: 10.1037/pmu0000030

Bangert, M., Peschel, T., Schlaug, G., Rotte, M., Drescher, D., Hinrichs, H., et al. (2006). Shared networks for auditory and motor processing in professional pianists: evidence from fMRI conjunction. *Neuroimage* 30, 917–926. doi: 10.1016/j.neuroimage.2005.10.044

Banissy, M. J., Sauter, D. A., Ward, J., Warren, J. E., Walsh, V., and Scott, S. K. (2010). Suppressing sensorimotor activity modulates the discrimination of auditory emotions but not speaker identity. *J. Neurosci.* 30, 13552–13557. doi: 10.1523/jneurosci.0786-10.2010

Batson, G. (2013). "Sharing creativity through the mirror neuron system: embodied simulation through dance," in *Creativity and Entrepreneurship: Changing Currents in Education and Public Life*, eds L Book and D. P. Phillips (Winston-Salem, NC: Wake Forest University), 66. doi: 10.4337/9780857937209.00015

Bekkali, S., Youssef, G. J., Donaldson, P. H., Albein-Urios, N., Hyde, C., and Enticott, P. G. (2020). Is the putative mirror neuron system associated with empathy? A systematic review and meta-analysis. *Neuropsychol. Rev.* 31, 14–57. doi: 10.1007/s11065-020-09452-6

Caicedo, D. G., and Van Beuzekom, M. (2006). *How Do You Feel? An Assessment of Existing Tools for the Measurement of Emotions and Their Application in Consumer Products Research*. Delft: Delft University of Technology.

Cattaneo, L., and Rizzolatti, G. (2009). The mirror neuron system. *Arch. Neurol.* 66, 557–560.

Cross, I., Laurence, F., and Rabinowitch, T.-C. (2012). "Empathy and creativity in group musical practices: towards a concept of empathic creativity," in *The Oxford Handbook of Music Education*, Vol. 2, eds, G. E. McPherson and G. F. Welch (Oxford: Oxford University Press).

Davis, M. H. (1980). A multidimensional approach to individual differences in empathy. *JSAS Catalog of Selected Documents in Psychol.* 10:85.

Davis, M. H. (1983). Measuring individual differences in empathy: evidence for a multidimensional approach. *J. Pers. Soc. Psychol.* 44:113. doi: 10.1037/0022-3514.44.1.113

Desmet, P. M., Hekkert, P., and Jacobs, J. J. (2000). "When a car makes you smile: development and application of an instrument to measure product emotions," in *ACR North American Advances*, Vol. 27, eds S. J. Hoch and R. J. Meyer (Provo, UT: Association for Consumer Research), 111–117.

Deutsch, D. (2016). Authentic assessment in music composition: feedback that facilitates creativity. *Music Educ. J.* 102, 53–59. doi: 10.1177/0027432115621608

Dutta, E., Bothra, A., Chaspari, T., Ioerger, T., and Mortazavi, B. J. (2020). "Reinforcement learning using EEG signals for therapeutic use of music in emotion management," in *Proceedings of the Paper Presented at the 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society* (Victoria: EMBC).

Fink, A., Reim, T., Benedek, M., and Grabner, R. H. (2020). The effects of a verbal and a figural creativity training on different facets of creative potential. *J. Creat. Behav.* 54, 676–685. doi: 10.1002/jocb.402

Form, S., and Kaernbach, C. (2018). More is not always better: the differentiated influence of empathy on different magnitudes of creativity. *Eur. J. Psychol.* 14:54. doi: 10.5964/ejop.v14i1.1432

Forti, S., Colombo, B., Clark, J., Bonfanti, A., Molteni, S., Crippa, A., et al. (2020). Soundbeam imitation intervention: training children with autism to imitate meaningless body gestures through music. *Adv. Autism* 6, 227–240. doi: 10.1108/aia-07-2019-0023

Fürst, G., and Grin, F. (2018). A comprehensive method for the measurement of everyday creativity. *Think. Skills Creativity* 28, 84–97. doi: 10.1016/j.tsc.2018.03.007

Garrido, S., and Schubert, E. (2011). Individual differences in the enjoyment of negative emotion in music: a literature review and experiment. *Music Percept.* 28, 279–296. doi: 10.1525/mp.2011.28.3.279

Gazzola, V., Aziz-Zadeh, L., and Keysers, C. (2006). Empathy and the somatotopic auditory mirror system in humans. *Curr. Biol.* 16, 1824–1829. doi: 10.1016/j.cub.2006.07.072

Gerry, L. J. (2017). Paint with me: stimulating creativity and empathy while painting with a painter in virtual reality. *IEEE Trans. Vis. Comput. Graph.* 23, 1418–1426. doi: 10.1109/tvcg.2017.2657239

Glaveanu, V., Lubart, T., Bonnardel, N., Botella, M., De Biaisi, P.-M., Desainte-Catherine, M., et al. (2013). Creativity as action: findings from five creative domains. *Front. Psychol.* 4:176. doi: 10.3389/fpsyg.2013.00176

Hou, J., Rajmohan, R., Fang, D., Kashfi, K., Al-Khalil, K., Yang, J., et al. (2017). Mirror neuron activation of musicians and non-musicians in response to motion captured piano performances. *Brain Cogn.* 115, 47–55. doi: 10.1016/j.bandc.2017.04.001

Jeon, H., and Lee, S.-H. (2018). From neurons to social beings: short review of the mirror neuron system research and its socio-psychological and psychiatric implications. *Clin. Psychopharmacol. Neurosci.* 16, 18–31. doi: 10.9758/cpn.2018.16.1.18

Jiang, J., Liu, F., Zhou, L., and Jiang, C. (2019). The neural basis for understanding imitation-induced musical meaning: the role of the human mirror system. *Behav. Brain Res.* 359, 362–369. doi: 10.1016/j.bbr.2018.11.020

Kawakami, A., and Katahira, K. (2015). Influence of trait empathy on the emotion evoked by sad music and on the preference for it. *Front. Psychol.* 6:1541. doi: 10.3389/fpsyg.2015.01541

Keaton, S. A. (2017). "Interpersonal Reactivity Index (IRI) (Davis, 1980)," in *The Sourcebook of Listening Research: Methodology and Measures*, eds D. L. Worthington and G. D. Bodie (Hoboken, NJ: John Wiley & Sons, Inc), 340–347. doi: 10.1002/9781119102991.ch34

Keysers, C., Kohler, E., Umiltà, M. A., Nanetti, L., Fogassi, L., and Gallese, V. (2003). Audiovisual mirror neurons and action recognition. *Exp. Brain Res.* 153, 628–636. doi: 10.1007/s00221-003-1603-5

Kilner, J. M., and Lemon, R. N. (2013). What we know currently about mirror neurons. *Curr. Biol.* 23, R1057–R1062.

Kohler, E., Keysers, C., Umilta, M. A., Fogassi, L., Gallese, V., and Rizzolatti, G. (2002). Hearing sounds, understanding actions: action representation in mirror neurons. *Science* 297, 846–848. doi: 10.1126/science.1070311

Lahav, A., Saltzman, E., and Schlaug, G. (2007). Action representation of sound: audiomotor recognition network while listening to newly acquired actions. *J. Neurosci.* 27, 308–314. doi: 10.1523/jneurosci.4822-06.2007

Lee, A., Legood, A., Hughes, D., Tian, A. W., Newman, A., and Knight, C. (2020). Leadership, creativity and innovation: a meta-analytic review. *Eur. J. Work Organ. Psychol.* 29, 1–35.

Li, H., Duan, H., Zheng, Y., Wang, Q., and Wang, Y. (2020). A CTR prediction model based on user interest via attention mechanism. *Appl. Intell.* 50, 1192–1203. doi: 10.1007/s10489-019-01571-9

Li, H., Li, F., and Chen, T. (2018). A motivational–cognitive model of creativity and the role of autonomy. *J. Bus. Res.* 92, 179–188. doi: 10.1016/j.jbusres.2018.07.025

Moreira, I. X., da Costa, A., Belo, L., dos Santos Gonçalves, A., and Savio, R. (2020). Impact of creativity and interest in learning on student achievement instituto superior cristal students. *ISCE J. Innov. Studies Charact. Educ.* 4, 70–78.

Morizio, L. J. (2021). *Creating Compassion: Harnessing Creativity for Empathy Development*. Boston: University of Massachusetts.

Paulus, P. B., and Nijstad, B. A. (2019). *The Oxford Handbook of Group Creativity and Innovation: Oxford Library of Psychology*. Oxford: Oxford University Press.

Pereira, C. S., Teixeira, J., Figueiredo, P., Xavier, J., Castro, S. L., and Brattico, E. (2011). Music and emotions in the brain: familiarity matters. *PLoS One* 6:e27241. doi: 10.1371/journal.pone.0027241

Peters, C., Pelachaud, C., Bevacqua, E., Mancini, M., and Poggi, I. (2005). "A model of attention and interest using gaze behavior," in *Proceedings of the Paper Presented at the International Workshop on Intelligent Virtual Agents*, Berlin.

Pulos, S., Elison, J., and Lennon, R. (2004). The hierarchical structure of the interpersonal reactivity index. *Soc. Behav. Pers.* 32, 355–360. doi: 10.2224/sbp.2004.32.4.355

Ramachandra, V., Depalma, N., and Lisiewski, S. (2009). The role of mirror neurons in processing vocal emotions: evidence from psychophysiological data. *Int. J. Neurosci.* 119, 681–691. doi: 10.1080/00207450802572188

Rietzschel, E. F., and Ritter, S. M. (2018). "Moving from creativity to innovation," in *Individual Creativity in the Workplace*, eds R. Reiter-Palmon and J. Kaufman (Amsterdam: Elsevier), 3–34. doi: 10.1016/b978-0-12-813238-8.00001-2

Rizzolatti, G. (2005). The mirror neuron system and its function in humans. *Anat. Embryol.* 210, 419–421. doi: 10.1007/s00429-005-0039-z

Sacharin, V., Schlegel, K., and Scherer, K. R. (2012). *Geneva Emotion Wheel Rating Study*. Geneva: University of Geneva.

Schäfer, T., and Sedlmeier, P. (2010). What makes us like music? Determinants of music preference. *Psychol. Aesthet. Creat. Arts* 4, 223–234. doi: 10.1037/a0018374

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Soc. Sci. Inf.* 44, 695–729. doi: 10.1177/0539018405058216

Scherer, K. R., Shuman, V., Fontaine, J., and Soriano Salinas, C. (2013). "*The GRID meets the wheel: assessing emotional feeling via self-report*," in *Components of Emotional Meaning: A Sourcebook*, eds J. J. R. Fontaine, K. R. Scherer, and C. Soriano (Oxford: Oxford University Press), 281–298. doi: 10.1093/acprof:oso/9780199592746.003.0019

Schnell, K., Bluschke, S., Konradt, B., and Walter, H. (2011). Functional relations of empathy and mentalizing: an fMRI study on the neural basis of cognitive empathy. *Neuroimage* 54, 1743–1754. doi: 10.1016/j.neuroimage.2010.08.024

Sittler, M. C., Cooper, A. J., and Montag, C. (2019). Is empathy involved in our emotional response to music? The role of the PRL gene, empathy, and arousal in response to happy and sad music. *Psychomusicology* 29:10. doi: 10.1037/pmu0000230

Sonnby-Borgström, M., Jönsson, P., and Svensson, O. (2003). Emotional empathy as related to mimicry reactions at different levels of information processing. *J. Nonverbal Behav.* 27, 3–23.

Stephan, M. A., Lega, C., and Penhune, V. B. (2018). Auditory prediction cues motor preparation in the absence of movements. *Neuroimage* 174, 288–296. doi: 10.1016/j.neuroimage.2018.03.044

Vuoskoski, J. K., Thompson, W. F., McIlwain, D., and Eerola, T. (2011). Who enjoys listening to sad music and why? *Music Percept.* 29, 311–317. doi: 10.1525/mp.2012.29.3.311

Warren, J. E., Sauter, D. A., Eisner, F., Wiland, J., Dresner, M. A., Wise, R. J., et al. (2006). Positive emotions preferentially engage an auditory–motor "mirror" system. *J. Neurosci.* 26, 13067–13075. doi: 10.1523/jneurosci.3907-06.2006

Webster, G. D., and Weir, C. G. (2005). Emotional responses to music: interactive effects of mode, texture, and tempo. *Motiv. Emot.* 29, 19–39. doi: 10.1007/s11031-005-4414-0

Wöllner, C. (2012). Is empathy related to the perception of emotional expression in music? A multimodal time-series analysis. *Psychol. Aesthet. Creat. Arts* 6, 214–223. doi: 10.1037/a0027392

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Statistical Properties of Musical Creativity: Roles of Hierarchy and Uncertainty in Statistical Learning

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Creativity is part of human nature and is commonly understood as a phenomenon whereby something original and worthwhile is formed. Owing to this ability, humans can produce innovative information that often facilitates growth in our society. Creativity also contributes to esthetic and artistic productions, such as music and art. However, the mechanism by which creativity emerges in the brain remains debatable. Recently, a growing body of evidence has suggested that statistical learning contributes to creativity. Statistical learning is an innate and implicit function of the human brain and is considered essential for brain development. Through statistical learning, humans can produce and comprehend structured information, such as music. It is thought that creativity is linked to acquired knowledge, but so-called "eureka" moments often occur unexpectedly under subconscious conditions, without the intention to use the acquired knowledge. Given that a creative moment is intrinsically implicit, we postulate that some types of creativity can be linked to implicit statistical knowledge in the brain. This article reviews neural and computational studies on how creativity emerges within the framework of statistical learning in the brain (i.e., statistical creativity). Here, we propose a hierarchical model of statistical learning: statistically chunking into a unit (hereafter and shallow statistical learning) and combining several units (hereafter and deep statistical learning). We suggest that deep statistical learning contributes dominantly to statistical creativity in music. Furthermore, the temporal dynamics of perceptual uncertainty can be another potential causal factor in statistical creativity. Considering that statistical learning is fundamental to brain development, we also discuss how typical versus atypical brain development modulates hierarchical statistical learning and statistical creativity. We believe that this review will shed light on the key roles of statistical learning in musical creativity and facilitate further investigation of how creativity emerges in the brain.

Keywords: statistical learning, prediction, creativity, development, hierarchy, abstraction, integration, autism spectrum disorder

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INTRODUCTION

Creativity is a process of producing something that is both original and worthwhile (Lubart and Mouchiroud, 2003; Kozbelt et al., 2010; Robert, 2011). It also contributes to the perception and production of information in new ways (Dailey et al., 1997; Furlong, 2009; Hargreaves, 2012). Creativity sometimes triggers innovation in science, technology, and arts, creating historical shifts in human society. Over a long period, many people have been fascinated by the question of how creativity emerges in the brain. There is no doubt that creativity is intricately linked to acquired knowledge; however, the underlying mechanisms remain unclear. In particular, there is little understanding of how novel and uncertain information emerges from acquired knowledge and why such uncertain information can be accepted as creative. Recently, a growing body of literature has suggested that *statistical learning* and the knowledge that results therefrom may underlie creativity (Wiggins, 2012, 2020; Daikoku, 2019a,b; Zioga et al., 2019).

Statistical learning is an implicit and innate function of the human brain and is essential for brain development (Saffran et al., 1996). The statistical learning system allows us to "predict" an upcoming phenomenon to minimize prediction error and resolve "perceptual uncertainty" (Friston, 2010; Clark, 2013; Hasson, 2017). More specifically, statistical learning involves a mechanism by which the brain calculates the transitional probability (i.e., local statistics) and uncertainty of its probability distribution (i.e., global statistics). Statistical learning ultimately allows the brain to optimize prior predictions and suppress uncertainty. Through statistical learning, humans acquire the ability to produce and comprehend structured sequences, such as music and language.

Evidence suggests that statistical learning also contributes to creative behaviors, such as music composition (Zioga et al., 2019). Creativity is often unpredictable and uncertain because of its novelty. Thus, creativity stemming from statistical learning (hereafter, *statistical creativity*) seems to conflict with the fundamental role of statistical learning: optimizing prior prediction and suppressing uncertainty (Clark, 2013; Hasson, 2017). One possible hypothesis is that a decrease in uncertainty could act as a reward (Van de Cruys and Wagemans, 2011). However, humans cannot pursue additional potential rewards from significantly less uncertain information (Berlyne, 1970). That is, humans are curious about uncertain information for the pursuit of potential rewards (Kagan, 1972). This novelty-seeking behavior encourages the perception and production of statistically uncertain and new information, resulting in a certain degree of increase in uncertainty. People expect potential rewards from novel information with a certain degree of uncertainty and may approve of creativity. In the end, human behavior may display "fluctuation" (temporal dynamics) of uncertainty under the competition between uncertainty resolution and the further pursuit of rewards.

This article reviews neural and computational studies on the emergence of statistical creativity in the brain. In particular, we propose a hierarchical model of statistical learning: statistically chunking into a unit (hereafter, "*shallow*" statistical learning) and combining several units (hereafter, "*deep*" statistical learning). We propose a hypothesis that deep statistical learning and the fluctuation of perceptual uncertainty dominantly contribute to statistical creativity. Considering that statistical learning is fundamental to brain development, we also discuss how typical versus atypical brain development modulates hierarchical statistical learning and statistical creativity. Finally, we explore musical statistical creativity and how it interacts with general creativity (e.g., thinking and idea generation).

FROM STATISTICAL LEARNING TO STATISTICAL CREATIVITY

Prediction and Statistical Learning

The brain is a learning machine that continually adapts to varying and uncertain environments worldwide. Through learning, the developing brain gradually becomes able to comprehend and produce structured information, such as music. Predictive coding, currently a predominant theory on sensory perception (Friston, 2010; Heilbron and Chait, 2018), provides a neurophysiological architecture of predictive learning processes in the human brain. Neural representations in the higher levels of cortical hierarchies can be used to predict plausible representations in the lower levels in a top-down manner and are then compared between the hierarchies to assess the prediction error (i.e., a mismatch between a prior prediction and the actual sensory input) (Mumford, 1992; Rao and Ballard, 1999; Kiebel et al., 2008). The resulting mismatched signal is passed back up the hierarchy to update higher representations and yield better predictions. Over the long term, this recursive exchange of signals reduces the prediction error and uncertainty in the environment. In this framework, the reliability of the prior prediction is also controlled by the precision (confidence) of prediction at higher levels of a hierarchical model (Friston, 2008). This precision can be estimated by the variance of any possible sensory input, which is sometimes referred to as *perceptual uncertainty* (information entropy, Shannon, 1948). In other words, the brain perceives and suppresses the uncertainty. The expected reduction of uncertainty has generally been referred to as *salience*, evaluated from the gap between the prior and posterior distributions (i.e., Kullback–Leibler divergence or relative entropy).

Statistical learning mechanisms in the brain appear to agree with this predictive process (Harrison et al., 2006). Statistical learning is an automatic computing system by which the human brain extracts statistical regularities from the world and predicts a future state to minimize sensory reactions and uncertainty over the environment. Specifically, the brain calculates the transitional probability and precisely perceives the uncertainty of its probability distribution. This internalized probabilistic model allows us to generate prior predictions of future states and continually update the internal model (prior distribution) for better prediction and precision (Daikoku et al., 2017) by integrating sensory input with prior distribution. Evidence has also suggested that human pitch prediction of novel melodies is closely linked to statistical models of transitional probability sampled from a large corpus of music (Pearce and Wiggins, 2006, 2012; Pearce et al., 2010). This may imply that human brains acquire a statistically universal model of music through musical statistical learning.

Some researchers have suggested two interdependent processes as hallmarks of statistical learning (Rogers and McClelland, 2004; Altmann, 2017; Daikoku, 2019a,b): the chunking of statistically coherent events and the sequential combination of the chunked units. They indicated that an individual's experience is abstracted on a statistical basis to generate a chunk that captures the statistical common and shareable denominator across individually experienced information (Sloutsky, 2010). This suggests that statistical learning underlying chunk formation and word acquisition consists of statistical accumulation across multiple episodes. However, an opposing statistical learning process appears to occur simultaneously: chunked units can be integrated to generate novel information through statistical learning (Altmann, 2017). Thus, language/music learning requires a route from the individual experience of statistical abstraction as a shareable knowledge unit (e.g., word), while comprehension and creation (e.g., grammar and sentences) require the integration of several units. Therefore, these two interdependent processes are necessary for a complete account of statistical learning and production that results therefrom (Thiessen et al., 2013; Wiggins and Sanjekdar, 2019; Wiggins, 2020).

Statistical Creativity

Recent studies claim that statistical learning contributes to creative behaviors and learning, such as music composition (Daikoku, 2019b; Zioga et al., 2019); however, the underlying mechanisms remain unclear. In this study, we refer as creativity stemming from statistical learning as statistical creativity and propose two potential keys to statistical creativity. The first is the interplay between the chunking of statistically coherent events into a unit and the integration of several units. This process forms a hierarchical structure in statistical learning (hierarchical statistical learning). The second is the fluctuation of the perceptual uncertainty. The brain appears to seek a suboptimal solution of uncertainty for creativity based on prior predictions, which results in fluctuations in uncertainty. Furthermore, it is assumed that these two key factors interact with each other.

Deep Statistical Learning

Statistical learning underlying chunk formation consists of statistical accumulation across multiple episodes, contributing to generalization and abstraction (shallow statistical learning). Alternatively, an opposing statistical learning process is as follows: the integration of the chunked units could allow not only for learning of relationships between units but also the "creation" of novel information (deep statistical learning). Through statistical integration, humans can create and perceive a novel episodic representation (Altmann, 2017). We hypothesize that this deep statistical learning has a potential link to statistical creativity.

This hypothesis has been investigated in neural (Daikoku et al., 2016, 2017) and computational studies (Daikoku, 2018b, 2019b,c,d; Daikoku and Yumoto, 2020). One useful model of creativity comes from musical improvisation, in which musicians spontaneously create novel melodies and rhythms. For example, based on a computational model of the brain's statistical learning, a study examined the statistical characteristics of jazz improvisation played by Bill Evans, Herbie Hancock, and McCoy Tyner, who are world-famous jazz pianists (Daikoku, 2018a,b). The results showed that small-scale statistical units have general characteristics shared among the three improvisers, whereas larger-scale statistical units provide individualities unique to each improviser (**Figure 1B**). This may suggest that small-scale (shallow) statistical learning (**Figure 1A**) fundamentally provides general and common knowledge, while large-scale (deep) statistical learning contributes to individual knowledge as well as common knowledge in musical creativity (Daikoku, 2019a,b). Given these findings, deep statistical learning may contribute mainly to individual phrasing or melody, while small-scale statistical learning may underlie the production of several tone transitions and consistent rhythm properties.

For example, jazz music has general regularities in chord sequences such as the so-called "two-five-one (II–V–I) progression." This is a common cadential chord sequence used in a wide variety of music genres, including jazz harmony. It is a succession of chords whose roots descend in fifths from the supertonic (II) to dominant (V), and finally to the tonic (I). Such syntactic progression frequently occurs in a jazz improvisation, and therefore, the statistics of the sequential information have high transitional probability and low uncertainty. Thus, once a person has learned the statistical characteristics, it can be chunked as a commonly used unit among improvisers. In contrast, the ways of combining the chunked units are different between improvisers and therefore represent the individuality of musical creativity (see **Figure 1**).

In this phrase of **Figure 1A**, the chord "IV" (E♭maj7) in the fourth measure corresponds to the chord "I" (E♭maj7) in the second measure occurring several chords earlier, creating a non-adjacent hierarchical dependency between "I" and "IV" in a recursive fashion. The local dependency between the first and second chords (E♭maj7 – B♭m7) is less likely according to traditional music theory, but this second chord lays the groundwork for the non-local dependency between "I" and "IV" by generating a II–V–I progression (i.e., B♭m7 – E♭7 – A♭maj7). Another type of interaction can be seen in the latter half of the phrase (i.e., adjacent: II – V – VI – IV, non-adjacent: IV –I). Near the end of the piece, the higher hierarchy of the harmony structure "I – IV (– IV) – I" nests the lower hierarchy of the structures "II–V–I" and "II–V–VI–IV." Hofstadter (1979) also indicated that a key change embedded in a superordinate key forms hierarchical non-adjacent structures in a recursive fashion. Thus, composers generally design hierarchical non-adjacent structures in a recursive fashion, potentially using this technique to organize the entire movement of a symphony or sonata (Schenker and Jonas, 1956).

To summarize, hierarchical statistical learning is as follows: The interplay between the chunking of statistically coherent events and the integration of several units could form hierarchically structured information, such as music. Hierarchical statistical learning is a window of these deeper processes that underpin creativity (Altmann, 2017). It is assumed that deep and large-scale statistical learning may contribute significantly to statistical creativity (**Table 1**). However, it is noteworthy that the individuality of musical representations does not necessarily contribute to musical creativity. Creativity is the process of producing new and worthwhile information.

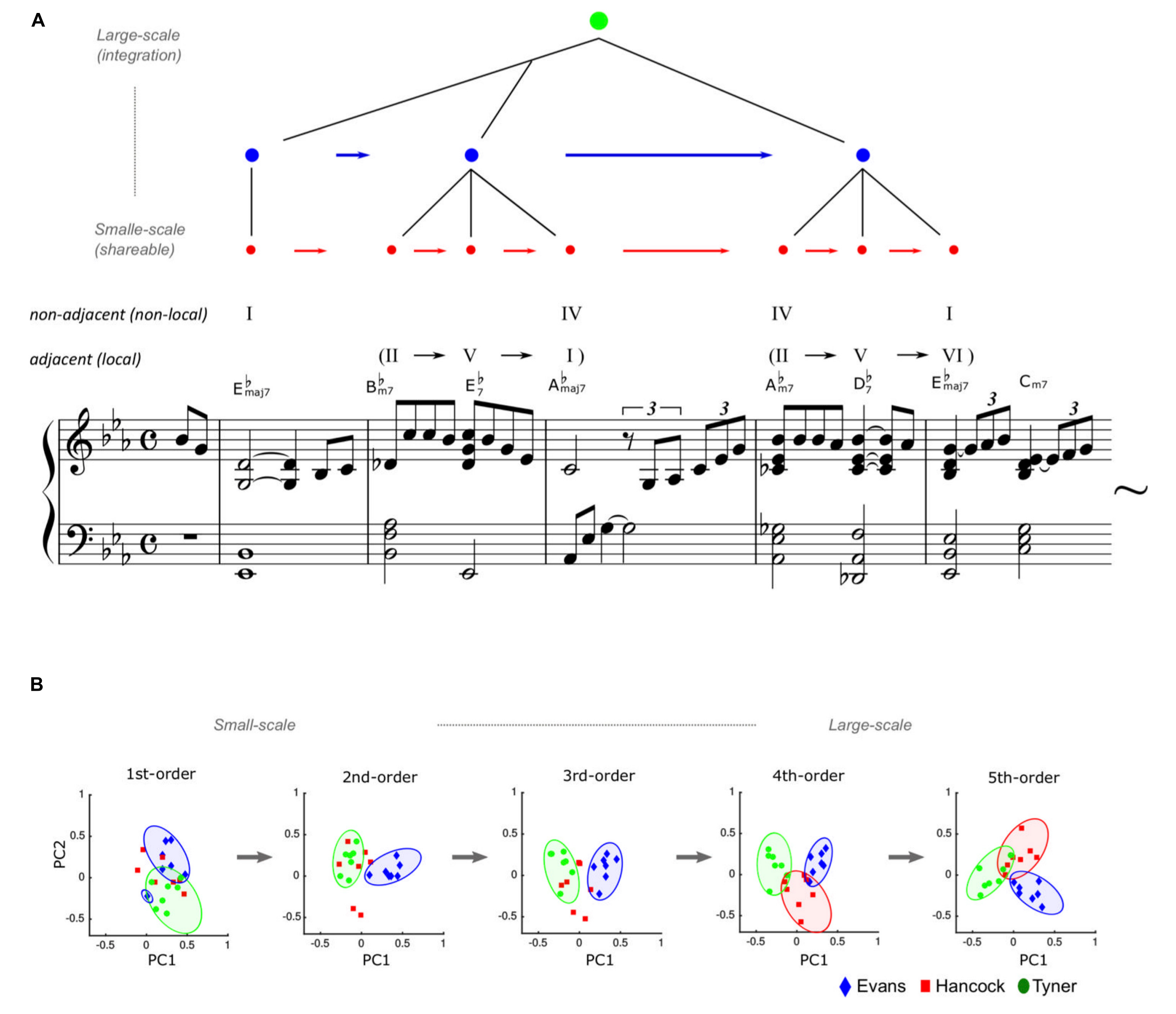

FIGURE 1 | Statistical creativity in musical improvisation. Misty by Errol Garner, composed in 1954. **(A)** The arrangement, chord names, and symbols are simplified (just major/minor, *flat*, and 7th note) to account for the two-five-one (II–V$^{(7)}$–*I*) progression. The statistical characteristics of jazz improvisation played by Bill Evans, Herbie Hancock, and McCoy Tyner. **(B)** Adapted from a figure of a previous article (Daikoku, 2018b). The component loading of principal component analyses showed that statistically coherent units have general characteristics shared among the three improvisors, whereas large-scale statistical units provide individualities unique to each improvisor. This suggests that abstraction (i.e., statistical learning within words) may fundamentally provide general knowledge, while integration (i.e., deep statistical learning between words) contributes to musical creativity and individuality, as well as common knowledge.

In this concept, a fixed representation of individual knowledge can also be interpreted as less creative and less uncertain. The flexibility of the presentation is crucial for producing novel and uncertain information. To discuss how the representation of individual knowledge that emerges from deep statistical learning interacts with their musical creativity, the next section proposes the second key to statistical learning: temporal dynamics of perceptual uncertainty.

Temporal Dynamics of Perceptual Uncertainty

Another key insight into statistical creativity is the fluctuation (temporal dynamics) of perceptual uncertainty. Perceptual uncertainty can generally be estimated by the variance of any possible sensory input (i.e., prior distribution; see section "Prediction and Statistical Learning"). The brain is motivated to optimize prior predictions and minimize uncertainty by learning (Friston, 2010). The decrease in uncertainty generally delivers pleasure, acting as a reward (Van de Cruys and Wagemans, 2011). In other words, humans are curious about uncertain information about potential rewards (Kagan, 1972). We hypothesize that such novelty-seeking behavior motivates the perception and production of novel and uncertain information. People are expected to receive potential rewards from novel and uncertain information and may approve such information as creativity.

TABLE 1 | Summary of our two proposed levels of statistical learning and statistical creativity.

	Deep	Flat (shallow)
Learning	Syntactic and integration of chunked units	Lexical, chunking, and abstraction
Memory	Large-scale and individual	Small-scale and shareable
Production	Creativity	Generality and commonality
Development	Typical ≠ atypical	Typical ≃ atypical

Through this competition between uncertainty resolution and the pursuit of rewards, human behavior may display fluctuations in uncertainty. Furthermore, perceptual uncertainty is based on sensory input, but it can also be an internal input. That is, the internal mental imagination of a new idea may also occur without sensory input, relying only on the uncertainty of the internalized statistical model.

Recent theories (Huron, 2006) and studies (Egermann et al., 2013; Koelsch, 2014; Gingras et al., 2016) suggest that the temporal dynamics of uncertainty may contribute to the esthetic appreciation of art and music and that this fluctuation may encourage humans to create and learn new regularities (Schmidhuber, 2006). For example, computational evidence shows that the uncertainty of music (conditional entropy of music sequence) fluctuates over a composer's lifetime (Daikoku, 2018d, 2019b). In these studies, across Beethoven's lifetime, the frequency of predictable patterns that are ubiquitous in his piano sonatas (familiar phrases) was found to decrease, whereas the entropy of statistical distribution gradually increased (**Figure 2**). Furthermore, these findings were more prominent in large-scale and deep statistical learning (see section "Deep Statistical Learning" and **Table 1**). This suggests that deep statistical learning is sensitive to the emergence of creativity as well as individuality. These findings may be explained from the viewpoint of the Wundt curve, as described by Berlyne (1970). This suggests that the hedonic value of complex stimuli tends to rise as they become less novel, while the opposite holds true for simple stimuli. This means that if familiarization of stimuli had proceeded further, the interestingness of the simple patterns would have continued to decline, whereas those of the complex patterns would have climbed to the peak of a Wundt curve. To summarize, creative behavior does not necessarily generate information—theoretically optimal, efficient, and certain information; instead, it sometimes gives rise to uncertain and unpredictable information.

What Is Musical Creativity?

We emphasize that statistical learning plays a key role in musical creativity. In particular, we propose two important roles for statistical learning in musical creativity. The first is a hierarchy of shallow and deep statistical learning. As discussed, small-scale (shallow) statistical learning (**Figure 1A**) may fundamentally provide general and common knowledge, while large-scale (deep) statistical learning contributes to individual knowledge of music (Daikoku, 2019a,b). In general, deep statistical learning is a mechanism for the integration of chunked units acquired by shallow statistical learning. That is, deep statistical learning of music could occur after persons have robust shallow statistical models of chunks. From the information theoretical perspective, as the order of transitional probability in the Markov chain becomes higher (i.e., the scale is larger), transition patterns can also be subdivided (for more detail, see Figure 3B of Daikoku, 2018c). That is, there are more sequential patterns in the deeper model. This leads to a diversity of patterns and individuality in music and possibly leads to musical creativity. Thus, deep statistical learning (integration of chunked units) may allow for the creation of a novel melody and rhythm even in the absence of any prior knowledge.

The second is a fluctuation in uncertainty. In general, creativity is defined as a process of producing something that is both original and worthwhile (Lubart and Mouchiroud, 2003; Kozbelt et al., 2010; Robert, 2011). Due to its novelty, creative information is often unpredictable and uncertain. It has been suggested that novel and uncertain musical information emerges through hierarchical statistical learning. However, there is still little understanding as to why such uncertain information can be accepted as creative. In other words, highly uncertain information is not necessarily creative. For example, a random tone sequence is highly uncertain, but in general, we do not approve of a random time sequence as creative music. Hence, it is assumed that appreciation of musical creativity may be associated with certain forms of suboptimality between uncertainty and certainty (**Figure 3**). We hypothesize that such competitive pursuits of uncertainty and certainty may induce fluctuations in uncertainty and that fluctuations in uncertainty may contribute to musical creativity.

Evidence has revealed that musicians are good statistical learners (Francois and Schön, 2011; Paraskevopoulos et al., 2012; Elmer and Lutz, 2018; Daikoku and Yumoto, 2020), allowing the brain to precisely grasp the temporal dynamics of uncertainty in music perception and production (Hansen and Pearce, 2014; Daikoku, 2019b; Zioga et al., 2019). We hypothesize that such proficiency in precision in perceptual uncertainty may also allow musicians to control the uncertainties in music finely by manipulating several musical components such as rhythm, melody, and harmony. Musical tensions can be created by establishing a predictable pattern in rhythm and melody and subsequently denying the prediction from it (Meyer, 2008). We can derive pleasure from deviant and uncertain musical patterns once a predictive pattern is established. Evidence suggests that so-called "music chills" are correlated with violations of expectation (Sloboda, 1991) and underpin musical appreciation (Huron, 2006). A neural study revealed that music chills increase brain activity in reward areas (ventral striatum) and decrease activity in the amygdala and ventromedial prefrontal cortex (Blood and Zatorre, 2001). This suggests that we derive rewards from violations of expectations, as well as from confirmed predictions. It is suggested that such esthetic appreciation can be reflected in the temporal dynamics of uncertainty.

Alternatively, musicians who have trained for a long period may have robust internal statistical models of music

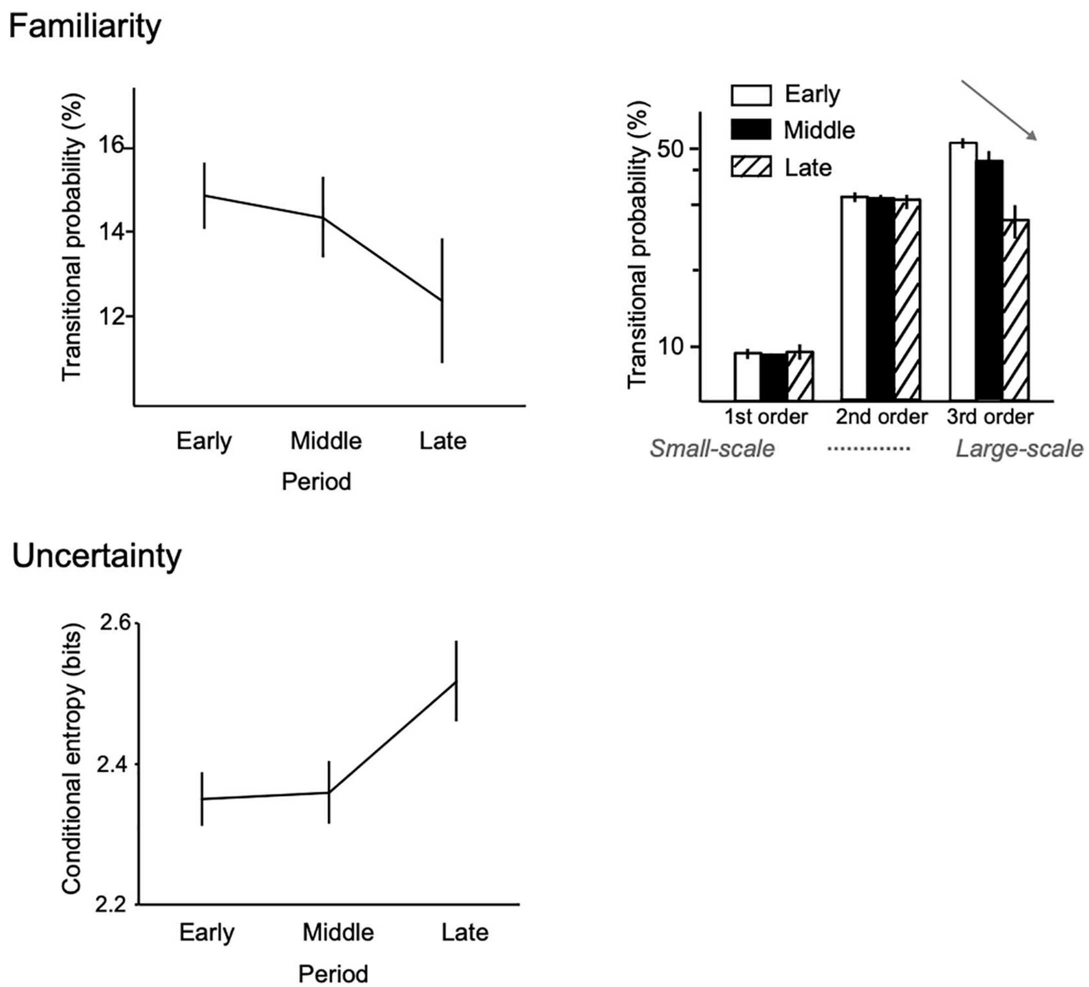

FIGURE 2 | Statistical creativity in the uncertainty fluctuation of musical composition. Figure adapted from a previous article (Daikoku, 2019b). From the early to the late periods of Beethoven's lifetime, the predictable patterns that ubiquitously appear in all of his piano sonatas (familiar sequence) were decreased, whereas the uncertainties were gradually increased. Further, these findings were more prominent in higher- (deeper), rather than lower-order statistical learning models (right). This may suggest that higher-order statistical learning reflects novelty-seeking (creative) behavior over a composer's lifetime.

(Hansen and Pearce, 2014). Furthermore, a study has suggested that the characteristics of internal models respond to one's own musical culture, such as Japanese and Western classical music (Daikoku et al., 2020). This may lead to cultural fixation of statistical knowledge and even bolster productivity instead of creativity. Statistical learning has been shown to be ubiquitously performed regardless of the intention (Perruchet and Pacton, 2006; Tsogli et al., 2019). This suggests that statistical knowledge is influenced by surrounding environmental information. Nevertheless, such musicians aptly exhibit pathways of high creativity (Kleinmintz, 2017; Przysinda et al., 2017; Zioga et al., 2019). One possible reason is that the knowledge and behavior that results from statistical learning involve implicit mechanisms with less intention (Perruchet and Pacton, 2006; Paraskevopoulos et al., 2012; Koelsch et al., 2016; Christiansen, 2019) but can transform into explicit knowledge through long-term training and experience (Batterink et al., 2015; Moser et al., 2020). Statistical learning of behavior is also considered as procedural learning that takes place without explicit knowledge (Kóbor et al., 2018). Therefore, we hypothesize that musical creativity resulting from statistical learning is mainly involved in intuitive performance, such as musical improvisation, in which musicians intuitively play new melodies and rhythms (Daikoku, 2018b).

Musical creativity is likely to be correlated with general creativity. A previous study examined how jazz improvisers, non-improvising musicians, and non-musicians perform the domain-general task of divergent thinking as well as the musical task of preference ratings for chord progressions that vary in expectation (Przysinda et al., 2017). The results showed that jazz musicians preferred unexpected (unpredicted) chord progressions. Further, the unexpected stimuli elicited larger music expectancy-related neural responses (early right-anterior negativity: ERAN) and another event-related potential (ERP) of P3b, followed by smaller long-latency responses (late positivity potential) in jazz musicians. This implies that people who can

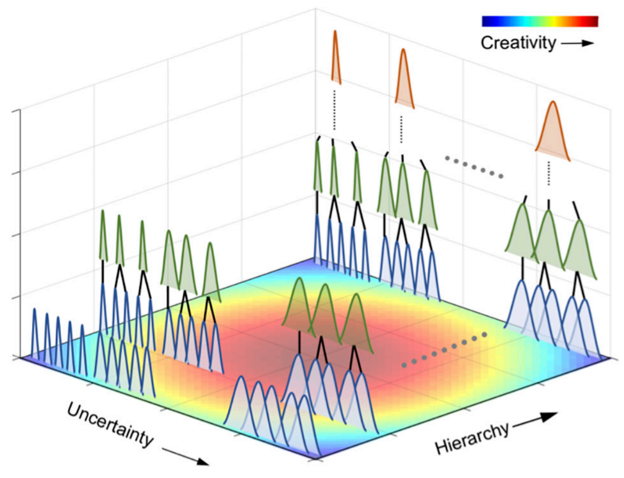

FIGURE 3 | A hypothesis of statistical creativity. Statistical creativity may, at least, be achieved via two potential mechanisms in a hierarchical statistical learning. The first is the interplay between the chunking of statistically coherent events into a unit and integration of the several units. This process forms a hierarchical structure in statistical learning (i.e., hierarchical statistical learning). The second is a perceptual uncertainty as shown in each of the bell-shaped distribution in the figure. The brain appears to seek a suboptimal solution of uncertainty for creativity based on prior distribution in the internal predictive model. It is assumed that a perceptual uncertainty at not very small- and large-scale statistical learning may induce statistical creativity.

predict precisely a musical event prefer an unpredictable one, possibly because they can correctly discriminate between familiar and novel musical events (i.e., creative). Notably, these neural effects were significantly correlated with fluency and originality in the divergent thinking task. This suggests that the precision of (prior) prediction is crucial for general and musical creativity.

NEURAL PERSPECTIVES OF STATISTICAL CREATIVITY

Recently, an increasing number of studies have suggested neural mechanisms of creativity. In particular, they showed that prefrontal function and some types of neural networks are associated with human creativity. In this section, by reviewing a number of neural studies, we discuss how the frontal functions and the three types of neuronal networks contribute to statistical learning and statistical creativity.

A Role of Frontal Cortex in Prior Prediction and Creativity

Frontal lobe functions are considered to be one of the most important keys to understanding creativity in the brain (Flaherty, 2005) and is generally involved in the top-down control of executive functions and decision-making (Gold and Shadlen, 2007; Dosenbach et al., 2008; Heekeren et al., 2008; Dalley et al., 2011). Recent studies have suggested that the prefrontal lobe (e.g., the inferior frontal gyrus, IFG) and dorsal connectivity between the prefrontal and sensory areas are associated with the formation of internal Bayesian models and prior predictions (Friston et al., 2016; Cope et al., 2017; Park et al., 2018). According to their studies, Bayesian models (i.e., prior prediction) could be generated in IFG and/or frontal motor speech regions and conveyed to auditory sensory regions through synaptic connections to instantiate plausible representations.

This hypothesis may also be explained by the developmental processes. A recent study indicated that this prefrontal-auditory connectivity is better developed in human adults than in newborns and macaques (Friederici et al., 2017). They also showed that in newborns, only the dorsal stream terminates in the premotor cortex (PMC). This partially supports the computational hypothesis that infants may have a prior prediction. That is, the development of the brain allows us to switch from a strong reliance on sensory input and weak reliance on prior predictions (hypo-prior) at an early learning stage to proper integration of sensory information with prior prediction (internal model) at later learning stages, becoming robust against disturbances in the uncertain phenomena (Philippsen and Nagai, 2019). Infants may have hypo-prior prediction due to the prematurity of dorsal prefrontal-sensory connectivity, which is essential for generating prior prediction and integrating prior prediction with sensory input. Together, many pieces of evidence suggest that prefrontal function may contribute to strong dependence on top-down prior prediction in perceiving and producing information. Such predictions can be generated by the acquired knowledge and experience. Hence, the strong dependence on prior prediction is partially interpreted as a strong reliance on certain acquired knowledge. Neural evidence has shown that both large- (deep) and small-scale (shallow) statistical learning involve top-down prior prediction (Daikoku et al., 2017). The magnetoencephalographic (MEG) study suggested that both mechanisms combine statistically chunks into a unit (small-scale statistical learning) and several units (large-scale statistical learning) that are reflected in mismatch responses.

However, prior predictions may sometimes inhibit creativity. Creativity is a phenomenon whereby something new and uncertain is formed, even if creativity is intricately linked to acquired knowledge. Therefore, the inhibition of prefrontal function may partially induce creative and uncertain information production (Chrysikou, 2018), possibly because of less dependence on prior prediction and certain knowledge. The neural evidence seems to agree with this hypothesis. Electroencephalography (EEG) (Fink et al., 2006, 2009; Lustenberger et al., 2015) and functional magnetic resonance imaging (fMRI) studies (Bengtsson et al., 2007; Berkowitz and Ansari, 2008; Limb and Braun, 2008; de Manzano and Ullén, 2012a,b) have examined brain activity during exposure to fixed melodies (less creative) or free-improvised melodies (more creative). The results indicate that more creative conditions lead to stronger alpha power (Fink et al., 2006; Lustenberger et al., 2015; Lopata et al., 2017) in the right frontal and parietal regions (Fink et al., 2009). The increased oscillatory activity in the alpha band is considered to reflect inhibition of the top-down process (Klimesch, 2012). However, other studies have suggested that alpha power reflects internally oriented attention, in which external bottom-up stimulation is also suppressed (Fink and Benedek, 2014). One study that investigated both the neural and genetic correlates of creativity suggested that a system of interaction between strong top-down and weak bottom-up processes underpins creativity, which is modulated by competition between the glutamate and GABA neurotransmitter systems (Liu et al., 2018). Furthermore, a computational model (Collins and Koechlin, 2012) inspired the hypothesis that the frontal lobes create an expanding repertoire of flexible behavioral strategies for driving action in uncertain, changing, and open-ended environments and suggested that frontal lobe function, including executive control and decision-making, somewhat supports the integration of reasoning, learning, and creativity through uncertainty monitoring. Green et al. (2017) also suggested that neural activity in the frontopolar cortex facilitates creative intelligence.

The contradiction between these two opposing findings on inhibition and enhancement of top-down control may be explained by the different tasks set in the different studies (Adhikari et al., 2016). In fMRI studies (Pinho et al., 2015), improvisation using a defined pitch set resulted in activation of the dorsolateral prefrontal cortex (dlPFC) because participants had to maintain available note choices in their working memory. In contrast, free improvisation leads to deactivation of the dlPFC because participants are able to take advantage of their implicit learning systems to create improvisations in which top-down control from the dlPFC would be disadvantageous (Dhakal et al., 2019). Using fMRI, Liu et al. (2015) examined brain mechanisms during poetry composition and the assessment (revision) process. The results indicated that dlPFC activity was attenuated during composition and reengaged during revision, whereas the medial prefrontal cortex (MPFC), which is associated with multiple cognitive functions such as motivation (Kouneiher et al., 2009) and unconscious decision-making (Soon et al., 2008), was active during both phases. Furthermore, expert poets showed significantly stronger deactivation of the dlPFC during composition, but there was no significant difference in the activity of the MPFC. Thus, expert poets may more effectively suspend top-down control while maintaining their motivation. Together, these findings show that open-ended creative and uncertain behaviors may suppress top-down controls, as expressed through the dlPFC activity level, while maintaining motivation, as expressed through MPFC activity level, whereas fixed behaviors enhance top-down control.

A Role of Neural Network in Temporal Dynamics of Perceptual Uncertainty and Creativity

Evidence suggests that the temporal dynamics of creativity processes are reflected in three types of neuronal networks (Beaty et al., 2018). First, the default mode network (DMN), which consists of the cortical midline and posterior inferior parietal regions, underpins spontaneous idea generation, episodic future thinking, and mind-wandering, among others (Mason et al., 2007; Zabelina and Andrews-Hanna, 2016). Second, the executive control network (ECN), which involves the lateral prefrontal and anterior inferior parietal regions, contributes to idea evaluation and executive function (Beaty et al., 2016). Third, the salience network (SN), which consists of the bilateral insula and anterior cingulate cortex, plays a role in conveying candidate ideas originating from the DMN to the ECN for idea evaluation (Beaty et al., 2016, 2018).

A previous study demonstrated that creative people show higher global efficiency within these networks, that is, a smaller number of paths traverse between brain regions (Beaty et al., 2015). In other words, the efficiency of the interplay between idea generation and evaluation is higher in creative people (Kleinmintz et al., 2019). Importantly, the perceptions of novelty (and surprise) are involved in both idea generation and evaluation processes, but not either of them; when generating a new idea, they need to recognize that it is a novel idea, not to mention when evaluating. This previous finding may explain the contradiction between inhibition and enhancement of frontal activity during creative behavior, as discussed in section A Role of Frontal Cortex in Prior Prediction and Creativity." Creative people have the ability to simultaneously engage these large-scale brain networks, including the DMN, ECN, and SN (Boccia et al., 2015; Beaty et al., 2018). It is assumed that creativity is not just free and uncontrolled activities but rather elaborate collaboration between uncontrolled/uncertain mind activity (i.e., DMN), which is less dependent on frontal function, and the top-down executive control of free thinking, including frontal function (i.e., ECN).

Together, the prefrontal function and three types of neural networks may have an important role in statistical creativity, particularly in terms of perceptual uncertainty. We hypothesize that the inhibition of prefrontal function may induce creative and uncertain information production, possibly because of the weakened dependence of prior knowledge. Besides, it is assumed that sophisticated creativity is not just free-thinking activities uncontrolled by prior knowledge but rather an elaborate collaboration between uncontrolled/uncertain mind activity (i.e., DMN), which is less dependent on frontal function, and top-down executive control of free thinking, including frontal function (i.e., ECN).

STATISTICAL CREATIVITY IN ATYPICAL DEVELOPMENT

Statistical learning is essential for brain development, as infants can implicitly perform statistical learning to acquire their native language (Teinonen et al., 2009). Computational studies allow modeling of the brain's developmental processes in predictive functions. Evidence suggests that the development of the brain allows us to switch from a strong reliance on the statistics of sensory input along with weak reliance on prior predictions (hypo-prior) to a proper integration of sensory statistics with prior prediction (internal model), thus becoming robust against disturbances in an uncertain environment (Philippsen and Nagai, 2019).

However, developmental disabilities, such as autism spectrum disorder (ASD), may develop different neural mechanisms underlying prior prediction (Nagai, 2019; Lanillos et al., 2020).

For example, some studies have suggested that individuals with ASD have hyper-plasticity in short-term statistical learning, such that they prefer recent sensory statistics rather than global (i.e., long term) statistical structures in sequential information (Sinha et al., 2014; Saffran, 2018). Thus, individuals with ASD are likely to show a strong reliance on sensory input and weak reliance on prior prediction (i.e., hypo-prior or hypersensitivity) in statistical learning. Notably, there is likely a contrastive type of abnormal development of predictive function: a stronger reliance on prior predictions (i.e., hyper-prior) (Philippsen and Nagai, 2019) than hypo-prior predictions (Pellicano and Burr, 2012). That is, the abnormality of prior prediction in ASD can be characterized by instability or variability, rather than either enhancement or decay, of reliance on prior prediction as compared to typical development (TD).

Such instability of reliance on prior prediction could also influence the precision of perceptual uncertainty because the precision is estimated by the variance of any sensory input (i.e., prior distribution). Some studies have indicated that ASD is susceptible to perceptual uncertainty (Boulter et al., 2014; Lawson et al., 2014; Van de Cruys et al., 2014). Uncertainty intolerance can be postulated as a key marker of generalized anxiety disorder (Freeston et al., 1994). The strong anxiety, observed as a common property of ASD, may also be explained by the intolerance of uncertainty and influence creativity (Baas et al., 2008). One study claims that such anxiety in ASD should emerge when environmental uncertainty is high (Boulter et al., 2014).

Thus, atypical brain development may exhibit specific characteristics (rather than decay or facilitation) of their statistical learning abilities. It is assumed that such specificity of statistical learning abilities could affect statistical creativity as well as prior prediction and perceptual uncertainty. A number of studies have reported that people with ASD sometimes exhibit superiority in some abilities (Boucher et al., 2012), such as mathematics, visual search skills (O'Riordan et al., 2001), and music and art skills (Happé and Frith, 2009; James, 2010). Furthermore, the right hemispheric networks are strongly dominant in ASD (Mason et al., 2008) and musicians (Zatorre et al., 2002). It has been thought that the right hemisphere function plays an important role in musical performance. It is possible that the dominance of the right hemisphere in individuals with ASD may influence their capacity for musical creativity.

A previous study showed that individuals with ASD can think of more unusual, uncertain ideas in divergent thinking tasks, although they produce fewer ideas than TD people (Best et al., 2015). Neural evidence may partially support this finding: the brain in ASD has hypoconnectivity between the prefrontal cortex and other areas (Belmonte et al., 2004; Just et al., 2004; Courchesne and Pierce, 2005; Green et al., 2020). Prior prediction mainly originates in frontal regions and is transmitted to sensory regions through synaptic connections (Cope et al., 2017; Park et al., 2018). The connectivity between the frontal and sensory areas is considered to play an essential role in conveying prior predictions to instantiate a plausible representation of sensory input. The brains of individuals with ASD may alter this connection (Belmonte et al., 2004; Just et al., 2004; Courchesne and Pierce, 2005; Green et al., 2020). This alteration leads to the modulation of the prior prediction. Nevertheless, the inhibition of prefrontal function may induce uncertain information production, possibly due to the modulation or depletion of prior prediction (hypo-prior).

Another key insight is deep and large-scale statistical learning (integration of chunked units). Evidence suggests that people with ASD display abnormalities in episodic memory representations (Goh and Peterson, 2012). Episodic representations are generally large-scale compared to semantic representations, such as words. A neuroimaging study also showed that the DMN, which is an important network for creativity, is altered in the brain in ASD; further, this alteration can lead to atypical integration of information about the self in relation to others (Padmanabhan et al., 2017). Furthermore, individuals with ASD may show inconsistent MMN responses to local (i.e., small-scale) deviants; some studies found weaker MMN in ASD than TD (Seri et al., 1999; Abdeltawwab and Baz, 2014; Bonnet-Brilhault et al., 2016), while other studies detected larger MMN in ASD than in TD (Gomot et al., 2002, 2011; Ferri et al., 2003; Lepistö et al., 2005; Green et al., 2020). Given these findings, individuals with ASD have either hyposensitivity or hypersensitivity to local sensory properties. In contrast, individuals with ASD seem to show consistent findings on global (i.e., large-scale) predictive processing: a study indicated weak MMN responses to global deviants (Goris et al., 2018). This may imply that ASD is hyposensitive to larger-scale statistical learning, while sensitivity to local events depends on the type of stimuli (Ide et al., 2017), representing either hypo/hypersensitivity to small-scale and local statistical learning.

In summary, atypical alterations in prior prediction and perceptual uncertainty may lead to individual characteristics of statistical creativity. Further research focused on the individuality of creativity that may illuminate the potential otherness of creative ability.

DISCUSSION

In this study, we propose a hierarchical model of statistical learning: statistically chunking into a unit (shallow statistical learning) and combining several units (deep statistical learning). We hypothesized that (**Table 1**):

- **(a)** *Large-scale statistical learning contributing to individual deep knowledge.*
- **(b)** *Temporal dynamics of uncertainty, representing a suboptimal solution for creativity.*

can be a potential causal factor in statistical creativity. **Figure 3** presents an overview of the hypotheses in this study. It is proposed that perceptual uncertainty at not exceedingly small- and large-scale statistical learning may induce statistical creativity. Statistical creativity may, at least, be achieved via two potential mechanisms. The first is the integration of the chunked units, which could allow not only for learning of relationships between units but also the "creation" of novel information ("*deep*" statistical learning).

That is, we can generate new information (e.g., sentences) by integrating common knowledge (e.g., words). This process also allows for a hierarchical structure in statistical learning. The second is the temporal dynamics (fluctuation) of perceptual uncertainty, as shown in each bell-shaped distribution in **Figure 3**. The brain appears to seek a suboptimal solution of uncertainty for creativity based on prior distribution. We also hypothesize that the first and second mechanisms of statistical creativity interact with each other. That is, the fluctuation of uncertainty may arise through the interplay between shallow and deep statistical learning, resulting in increased uncertainty.

It is also noteworthy that the two factors of statistical creativity are potentially correlated with neural bases. The prefrontal function and three types of neural networks may play an important role in statistical creativity, particularly in terms of perceptual uncertainty. The suppression of prefrontal function may induce creative and uncertain information production, possibly because of the weakened dependence on prior knowledge. However, elaborated creativity is not just free and uncertain thinking with less contribution from prior knowledge, but rather a collaboration between free thinking and certain prior knowledge. It is assumed that such collaboration is partially reflected in the temporal dynamics of uncertainty in a certain degree of deep statistical creativity (**Figure 3**).

Statistical learning is thought to be a domain-general and species-general learning principle that occurs for visual and auditory information, including language and music, and in both primates and non-primates, such as songbirds (Lu and Vicario, 2014, 2017), monkeys (Saffran et al., 2008), and rats (Toro et al., 2005). The current statistical learning hypothesis, however, may not be sufficient to cover all levels of music processing, including domain-specific mechanisms such as universal grammar, tonal pitch spaces, and hierarchical tension (Hauser et al., 2002; Jackendoff and Lerdahl, 2006). Some studies suggest that there are two steps in the learning process (Jusczyk, 1999; Ellis, 2009). The first is statistical learning, which shares a common mechanism among all domains (domain generality). The second is domain-specific learning, which has different mechanisms in each domain (domain specificity). Nevertheless, it is still unknown how statistical learning interacts with domain-specific learning, how various aspects of statistical learning (i.e., abstraction of statistically coherent events vs. combining the chunked units and shallow and deep levels) are linked to top-down and bottom-up processes of the brain, and how statistical knowledge can be used in creativity. Further, although creativity is associated with perception as well as production (Dailey et al., 1997; Furlong, 2009), no study has fully revealed the precise distinctions between creative production and perception (Hargreaves, 2012) from a statistical learning framework.

Categorization (Jones and Mewhort, 2007) and non-adjacent dependency (Frost and Monaghan, 2016) are likely to be the key mechanisms for understanding these questions. For example, humans learn the transitional probabilities of word categories, such as nouns and verbs (Jones and Mewhort, 2007); when the verb "drink" occurs, the brain predicts many subsequent words which can be drunk. The brain can also generalize both adjacent and non-adjacent statistical rules of grammar and apply these rules to novel vocabulary (Gomez and Gerken, 1999). Using such mechanisms, the brain does not have to code all the received information, contributing to memory capacity and uncertainty reduction. We hypothesize that this information efficiency encourages humans to produce uncertain and creative information. Future studies are necessary to demonstrate the roles of hierarchical statistical learning in categorization and non-adjacent dependency.

Notably, the current statistical creativity model does not fully explain all the components necessary to be accepted as creativity. Creativity is the process of producing something worthwhile as well as original (Lubart and Mouchiroud, 2003; Kozbelt et al., 2010; Robert, 2011). Despite the evidence on the contribution of statistical learning to the production of new and uncertain information, little is understood about how and why people can recognize such information as worthwhile and creative. A recent neural study demonstrated that uncertainty and surprise jointly predict musical pleasure reflected in the amygdala and hippocampus (Cheung et al., 2019). This study suggested that musical chord with high uncertainty but low surprise, and vice versa, evoked high pleasure. Given the previous findings, we hypothesize that not remarkably high and low uncertainty can be recognized as creative and valuable information. This fundamental question will be key to understanding why people can recognize uncertain information as worthwhile and novel.

Hierarchical statistical learning may be a key insight into examining the influence of dispositional, maturational, and developmental factors of the individuality of creative ability in the brain with developmental disorders such as ASD. Statistical learning is an innate mechanism that is facilitated by postnatal musical training (Francois and Schön, 2011; François et al., 2012; Paraskevopoulos et al., 2012; Daikoku et al., 2020). There is inconsistent evidence suggesting the enhancement and reduction of statistical learning ability in brains with ASD (Gomot et al., 2011; Roser et al., 2015; Goris et al., 2018; Green et al., 2020), which is generally thought to be associated with a combination of genetic and environmental factors (Chaste and Leboyer, 2012). A previous study proposed a neurocognitive model of competence development (Seither-Preisler et al., 2014), which describes the interaction between dispositional factors, natural maturation, and training-induced neural plasticity. The authors claimed that in the case of music processing, the morphology of the auditory cortex (bottom right) and the source waveforms of the early ERP component (P1) represent dispositional and training-induced factors, respectively. A neural network that is important for creativity (i.e., DMN) has also been considered to be associated with both genetic (Meda et al., 2014) and training factors (Taylor et al., 2013). Thus, dispositional, maturational, and learning-induced factors may play a key role in the development and emergence of statistical creativity. Future research is needed to investigate how prior dispositions interact with the influence of postnatal training. We believe that this review will shed light on the key roles of statistical learning in musical creativity and facilitate further investigation on how the development of the brain modulates creativity.

CONCLUDING REMARKS

Musical creativity is ubiquitous and unique to humans. The interaction between musical creativity and the brain is complex and involves a variety of neural circuits underlying sensory perception, learning, memory, action, and creativity. We emphasize that musical creativity engages "hierarchical" statistical learning. In particular, we propose two components that give rise to creativity. The first is deep statistical learning (integration of shareable units). The second is the temporal dynamics (fluctuation) of perceptual uncertainty. Considering evidence that the brains of individuals with ASD are susceptible to uncertainty, we assert that creativity in ASD can covertly reflect more (internally oriented) emotional representations against uncertainty and generation of creative and individual episodic information. Further research focused on the hierarchy of statistical learning and temporal dynamics of perceptual uncertainty may provide new insights into musical and general creativity in atypical and typical brains.

AUTHOR CONTRIBUTIONS

TD prepared the figures and wrote the original draft of the manuscript. GW and YN reviewed and edited the manuscript. TD, GW, and YN wrote the final manuscript. All authors contributed to the article and approved the submitted version.

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REFERENCES

Abdeltawwab, M., and Baz, H. (2014). Automatic pre-attentive auditory responses: MMN to tone burst frequency changes in autistic school-age children. *J. Int. Adv. Otol.* 11:438. doi: 10.5152/iao.2014.438

Adhikari, B. M., Norgaard, M., Quinn, K. M., Ampudia, J., Squirek, J., and Dhamala, M. (2016). The brain network underpinning novel melody creation. *Brain Connect.* 6, 772–785. doi: 10.1089/brain.2016.0453

Altmann, G. (2017). Abstraction and generalisation in statistical learning: implications for the relationship between semantic types and episodic tokens. *Philos. Trans. R. Soc. B Biol. Sci.* 372:20160060. doi: 10.1098/rstb.2016.0060

Assaneo, M. F., Ripollés, P., Orpella, J., Lin, W. M., de Diego-Balaguer, R., and Poeppel, D. (2019). Spontaneous synchronisation to speech reveals the neural mechanisms that facilitate language learning. *Nat. Neurosci.* 22, 627–632. doi: 10.1038/s41593-019-0353-z

Baas, M., De Dreu, C. K. W., and Nijstad, B. A. (2008). A meta-analysis of 25 years of mood-creativity research: hedonic tone, activation, or regulatory focus? *Psychol. Bull.* 134, 779–806. doi: 10.1037/a0012815

Batterink, L. J., Reber, P. J., and Paller, K. A. (2015). Functional differences between statistical learning with and without explicit training. *Learn. Mem.* 22, 544–556. doi: 10.1101/lm.037986.114

Beaty, R. E., Benedek, M., Barry Kaufman, S., and Silvia, P. J. (2015). Default and executive network coupling supports creative idea production. *Sci. Rep.* 5:10964.

Beaty, R. E., Benedek, M., Silvia, P. J., and Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends Cogn. Sci.* 20, 87–95. doi: 10.1016/j.tics.2015.10.004

Beaty, R. E., Kenett, Y. N., Christensen, A. P., Rosenberg, M. D., Benedek, M., Chen, Q., et al. (2018). Robust prediction of individual creative ability based on brain functional connectivity. *Proc. Nat. Acad. Sci.* 7:201713532.

Belmonte, M. K., Allen, G., Beckel-Mitchener, A., Boulanger, L. M., Carper, R. A., and Webb, S. J. (2004). Autism and abnormal development of brain connectivity. *J. Neurosci.* 24, 9228–9231. doi: 10.1523/jneurosci.3340-04.2004

Bengtsson, S. L., Csíkszentmihályi, M., and Ullén, F. (2007). Cortical regions involved in the generation of musical structures during improvisation in pianists. *J. Cogn. Neurosci.* 19, 830–842. doi: 10.1162/jocn.2007.19.5.830

Berkowitz, A. L., and Ansari, D. (2008). Generation of novel motor sequences: the neural correlates of musical improvisation. *NeuroImage* 41, 535–543. doi: 10.1016/j.neuroimage.2008.02.028

Berlyne, D. E. (1970). Novelty, complexity, and hedonic value. *Percept. Psychophys.* 8, 279–286. doi: 10.3758/bf03212593

Best, C., Arora, S., Porter, F., and Doherty, M. (2015). The relationship between subthreshold autistic traits, ambiguous figure perception, and divergent thinking. *J. Autism Dev. Disord.* 45, 4064–4073. doi: 10.1007/s10803-015-2518-2

Blood, A. J., and Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proc. Natl. Acad. Sci. U.S.A.* 98, 11818–11823. doi: 10.1073/pnas.191355898

Boccia, M., Piccardi, L., Palermo, L., Nori, R., and Palmiero, M. (2015). Where do bright ideas occur in the brain? meta-analytic evidence from neuroimaging studies of domain-specific creativity. *Front. Psychol.* 6:1195.

Bonnet-Brilhault, F., Alirol, S., Blanc, R., Bazaud, S., Marouillat, S., Thépault, R.-A., et al. (2016). GABA/Glutamate synaptic pathways targeted by integrative genomic and electrophysiological explorations distinguish autism from intellectual disability. *Mol. Psychiatry* 21, 411–418. doi: 10.1038/mp.2015.75

Boucher, J., Mayes, A., and Bigham, S. (2012). Memory in autism spectrum disorder. *Psychol. Bull.* 138:458.

Boulter, C., Freeston, M., South, M., and Rodgers, J. (2014). Intolerance of uncertainty as a framework for understanding anxiety in children and adolescents with ASD spectrum disorders. *J. Autism Dev. Disord.* 44, 1391–1402. doi: 10.1007/s10803-013-2001-x

Chaste, P., and Leboyer, M. (2012). Autism risk factors: genes, environment, and gene-environment interactions. *Dialogues Clin. Neurosci.* 14, 281–292. doi: 10.31887/dcns.2012.14.3/pchaste

Cheung, V. K. M., Harrison, P. M. C., Meyer, L., Pearce, M. T., Haynes, J.-D., and Koelsch, S. (2019). Uncertainty and surprise jointly predict musical pleasure and amygdala, hippocampus, and auditory cortex activity. *Curr. Biol.* 29, 4084–4092.e4.

Christiansen, M. H. (2019). Implicit statistical learning: a tale of two literatures. *Top. Cogn. Sci.* 11, 468–481.

Chrysikou, E. G. (2018). "Seventeen costs and benefits of cognitive control for creativity," in *The Cambridge Handbook of Neuroscience of Creativity*, eds R. E. Jung and O. Vartanian (Cambridge: Cambridge University Press).

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behav. Brain Sci.* 36, 181–204.

Collins, A., and Koechlin, E. (2012). Reasoning, learning, and creativity: frontal lobe function and human decision-making. *PLoS Biol.* 10:e1001293. doi: 10.1371/journal.pbio.1001293

Cope, T. E., Sohoglu, E., Sedley, W., Patterson, K., Jones, P. S., Wiggins, J., et al. (2017). Evidence for causal top-down frontal contributions to predictive processes in speech perception. *Nat. Commun.* 8:2154.

Courchesne, E., and Pierce, K. (2005). Why the frontal cortex in autism might be talking only to itself: local over-connectivity but long-distance disconnection. *Curr. Opin. Neurobiol.* 15, 225–230. doi: 10.1016/j.conb.2005.03.001

Daikoku, T. (2018a). Entropy, uncertainty, and the depth of implicit knowledge on musical creativity: computational study of improvisation in melody and rhythm. *Front. Comput. Neurosci.* 12:97.

Daikoku, T. (2018b). Musical creativity and depth of implicit knowledge: spectral and temporal individualities in improvisation. *Front. Comput. Neurosci.* 12:89.

Daikoku, T. (2018c). Neurophysiological markers of statistical learning in music and language: hierarchy, entropy, and uncertainty. *Brain Sci.* 8:114. doi: 10.3390/brainsci8060114

Daikoku, T. (2018d). Time-course variation of statistics embedded in music: corpus study on implicit learning and knowledge. *PLoS One* 13:e0196493. doi: 10.1371/journal.pone.0196493

Daikoku, T. (2019a). Computational models and neural bases of statistical learning in music and language: comment on "creativity, information, and consciousness: the information dynamics of thinking" by Wiggins. *Physics Life Rev.* 35, 48–51. doi: 10.1016/j.plrev.2019.09.001

Daikoku, T. (2019b). Depth and uncertainty of statistical knowledge on musical creativity fluctuate over a composer's lifetime. *Front. Comput. Neurosci.* 13:27.

Daikoku, T. (2019c). Statistical learning and uncertainty of melody and bass lines in music. *PLoS One* 14:e0226734. doi: 10.1371/journal.pone.0226734

Daikoku, T. (2019d). Tonality tunes the statistical characteristics of music: computational approaches to statistical learning. *Front. Comput. Neurosci.* 13:70.

Daikoku, T., and Yumoto, M. (2020). Musical expertise facilitates statistical learning of rhythm and perceptual uncertainty: a cross-cultural study. *Neuropsychologia* 146:1075537553.

Daikoku, T., Yatomi, Y., and Yumoto, M. (2020). Statistical learning of music- and language-like sequences and tolerance for spectral shifts. *Neurobiol. Learn. Mem.* 118, 8–19. doi: 10.1016/j.nlm.2014.11.001

Daikoku, T., Yatomi, Y., and Yumoto, M. (2016). Pitch-class distribution modulates the statistical learning of atonal chord sequences. *Brain Cogn.* 108, 1–10. doi: 10.1016/j.bandc.2016.06.008

Daikoku, T., Yatomi, Y., and Yumoto, M. (2017). Statistical learning of an auditory sequence and reorganisation of acquired knowledge: a time course of word segmentation and ordering. *Neuropsychologia* 95.

Dailey, A., Martindale, C., and Borkum, J. (1997). Creativity, synesthesia, and physiognomic perceptions. *Creat. Res. J.* 10, 1–8. doi: 10.1207/s15326934crj1001_1

Dalley, J. W., Everitt, B. J., and Robbins, T. W. (2011). Impulsivity, compulsivity, and top-down cognitive control. *Neuron* 69, 680–694. doi: 10.1016/j.neuron.2011.01.020

de Manzano, Ö, and Ullén, F. (2012a). Activation and connectivity patterns of the pre-supplementary and dorsal premotor areas during free improvisation of melodies and rhythms. *NeuroImage* 63, 272–280. doi: 10.1016/j.neuroimage.2012.06.024

de Manzano, Ö, and Ullén, F. (2012b). Goal-independent mechanisms for free response generation: creative and pseudo-random performance share neural substrates. *NeuroImage* 59, 772–780. doi: 10.1016/j.neuroimage.2011.07.016

Dhakal, K., Norgaard, M., Adhikari, B. M., Yun, K. S., and Dhamala, M. (2019). Higher node activity with less functional connectivity during musical improvisation. *Brain Connect.* 9, 296–309. doi: 10.1089/brain.2017.0566

Dosenbach, N. U. F., Fair, D. A., Cohen, A. L., Schlaggar, B. L., and Petersen, S. E. (2008). Dual-network architecture of top-down control. *Trends Cogn. Sci.* 12, 99–105. doi: 10.1016/j.tics.2008.01.001

Egermann, H., Pearce, M. T., Wiggins, G. A., and McAdams, S. (2013). Probabilistic models of expectation violation predict psychophysiological emotional responses to live concert music. *Cogn. Affect. Behav. Neurosci.* 13, 533–553. doi: 10.3758/s13415-013-0161-y

Ellis, R. (2009). "Implicitand explicit learning, knowledge, and instruction," in *Implicit and Explicit Knowledge in Second Language Learning, Testing, and Teaching*, eds R. Ellis, S. Loewen, C. Elder, R. Erlam, J. Philip, and H. Reinders (Bristol: Multilingual Matters).

Elmer, S., and Lutz, J. (2018). Relationships between music training, speech processing, and word learning: a network perspective. *Ann. N. Y. Acad. Sci.* doi: 10.1111/nyas.13581 Online ahead of print.

Ferri, R., Elia, M., Agarwal, N., Lanuzza, B., Musumeci, S. A., and Pennisi, G. (2003). The mismatch negativity and the P3a components of the auditory event-related potentials in autistic low-functioning subjects. *Clin. Neurophysiol.* 114, 1671–1680. doi: 10.1016/S1388-2457(03)00153-6

Fink, A., and Benedek, M. (2014). EEG alpha power and creative ideation. *Neurosci. Biobehav. Rev.* 44, 111–123. doi: 10.1016/j.neubiorev.2012.12.002

Fink, A., Grabner, R. H., Benedek, M., and Neubauer, A. C. (2006). Divergent thinking training is related to frontal EEG alpha synchronisation. *Eur. J. Neurosci.* 23, 2241–2246. doi: 10.1111/j.1460-9568.2006.04751.x

Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., et al. (2009). The creative brain: investigation of brain activity during creative problem solving using EEG and fMRI. *Hum. Brain Mapp.* 30, 734–748. doi: 10.1002/hbm.20538

Flaherty, A. W. (2005). Frontotemporal and dopaminergic control of idea generation and creative drive. *J. Comp. Neurol.* 493, 147–153. doi: 10.1002/cne.20768

Francois, C., and Schön, D. (2011). Musical expertise boosts implicit learning of both musical and linguistic structures. *Cereb. Cortex* 21, 2357–2365. doi: 10.1093/cercor/bhr022

François, C., Chobert, J., Besson, M., and Schön, D. (2012). Music training for the development of speech segmentation. *Cereb. Cortex* 23, 2038–2043. doi: 10.1093/cercor/bhs180

Freeston, M. H., Rhéaume, J., Letarte, H., Dugas, M. J., and Ladouceur, R. (1994). Why do people worry? *Pers. Individual Differ.* 17, 791–802.

Friederici, A. D., Chomsky, N., Berwick, R. C., Moro, A., and Bolhuis, J. J. (2017). Language, mind, and brain. *Nat. Hum. Behav.* 1, 713–722.

Friston, K. (2008). Hierarchical models of the brain. *PLoS Comput. Biol.* 4:e1000211.

Friston, K. (2010). Free-energy principle: a unified brain theory. *Nat. Rev. Neurosci.* 11, 127–138. doi: 10.1038/nrn2787

Friston, K., FitzGerald, T., Rigoli, F., Schwartenbeck, P. O., Doherty, J., and Pezzulo, G. (2016). Active inference and learning. *Neurosci. Biobehav. Rev.* 68, 862–879.

Frost, R. L. A., and Monaghan, P. (2016). Simultaneous segmentation and generalisation of nonadjacent dependencies from continuous speech. *Cognition* 147, 70–74. doi: 10.1016/j.cognition.2015.11.010

Furlong, A. (2009). The relation of plurilingualism/culturalism to creativity: a matter of perception. *Int. J. Multiling* 6, 343–368. doi: 10.1080/14790710903124997

Gingras, B., Pearce, M. T., Goodchild, M., Dean, R. T., Wiggins, G., and McAdams, S. (2016). Linking melodic expectations to expressive performance timing and perceived musical tension. *J. Exp. Psychol. Hum. Perc. Perform.* 42, 594–609. doi: 10.1037/xhp0000141

Goh, S., and Peterson, B. S. (2012). Imaging evidence for disturbances in multiple learning and memory systems in persons with autism spectrum disorders. *Dev. Med. Child Neurol.* 54, 208–213. doi: 10.1111/j.1469-8749.2011.04153.x

Gold, J. I., and Shadlen, M. N. (2007). Neural basis of decision-making. *Annu. Rev. Neurosci.* 30, 535–574.

Gomez, R. L., and Gerken, L. A. (1999). Artificial grammar learning by one-year-olds leads to specific and abstract knowledge. *Cognition* 70, 109–136. doi: 10.1016/s0010-0277(99)00003-7

Gomot, M., Blanc, R., Clery, H., Roux, S., Barthelemy, C., and Bruneau, N. (2011). Candidate electrophysiological endophenotypes of hyper-reactivity to change in autism. *J. Aut. Dev. Disord.* 41, 705–714. doi: 10.1007/s10803-010-1091-y

Gomot, M., Giard, M.-H., Adrien, J.-L., Barthelemy, C., and Bruneau, N. (2002). Hypersensitivity to acoustic change in children with autism: electrophysiological evidence of left frontal cortex dysfunctioning. *Psychophysiology* 39, 577–584. doi: 10.1111/1469-8986.3950577

Goris, J., Braem, S., Nijhof, A. D., Rigoni, D., Deschrijver, E., Van de Cruys, S., et al. (2018). Sensory prediction errors are less modulated by global context in autism spectrum disorder. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 3, 667–674. doi: 10.1016/j.bpsc.2018.02.003

Green, A. E., Spiegel, K. A., Giangrande, E. J., Weinberger, A. B., Gallagher, N. M., and Turkeltaub, P. E. (2017). Thinking cap plus thinking zap: Tdcs of the frontopolar cortex improves creative analogical reasoning and facilitates conscious augmentation of state creativity in verb generation. *Cereb. Cortex* 27, 2628–2639.

Green, H. L., Shuffrey, L., Levinson, L., Shen, G., Avery, T., Randazzo Wagner, M., et al. (2020). Evaluation of mismatch negativity as a biomarker for language impairment in autism spectrum disorder. *J. Commun. Disord.* 87:105997. doi: 10.1016/j.jcomdis.2020.105997

Hansen, N. C., and Pearce, M. T. (2014). Predictive uncertainty in auditory sequence processing. *Front. Psychol.* 5:1052.

Happé, F., and Frith, U. (2009). The beautiful otherness of the autistic mind. *Philos. Trans. R. Soc. London. Ser. B Biol. Sci.* 364, 1346–1350.

Hargreaves, D. J. (2012). Musical imagination: perception and production, beauty, and creativity. *Psychol. Music* 40, 539–557. doi: 10.1177/0305735612444893

Harrison, L. M., Duggins, A., and Friston, K. J. (2006). Encoding the uncertainty in the hippocampus. *Neural Netw.* 19, 535–546. doi: 10.1016/j.neunet.2005.11.002

Hasson, U. (2017). Neurobiology of uncertainty: implications for statistical learning. *Philos. Trans. R. Soc. B* 372:20160048. doi: 10.1098/rstb.2016.0048

Hauser, M. D., Chomsky, N., and Fitch, W. T. (2002). The faculty of language: what is it, who has it, and how did it evolve? *Science* 298, 1569–1579. doi: 10.1126/science.298.5598.1569

Heekeren, H. R., Marrett, S., and Ungerleider, L. G. (2008). Neural systems that mediate human perceptual decision-making. *Nat. Rev. Neurosci.* 9, 467–479. doi: 10.1038/nrn2374

Heilbron, M., and Chait, M. (2018). Great expectations: is there evidence for predictive coding in the auditory cortex? *Neuroscience* 389, 54–73. doi: 10.1016/j.neuroscience.2017.07.061

Hofstadter, D. (1979). *Gödel, Escher, Bach: an Eternal Golden Braid*. New York: Basic Books.

Huron, D. (2006). *Sweet Anticipation: Music and the Psychology of Expectation*, vol. 1. Cambridge, MA: MIT Press.

Ide, M., Yaguchi, A., Atsumi, T., Yasu, K., and Wada, M. (2017). Hypersensitivity is an extraordinarily high temporal processing in individuals with autism spectrum disorders. *Brain and nerve= Shinkei kenkyu no Shinpo* 69, 1281–1289.

Jackendoff, R., and Lerdahl, F. (2006). The capacity for music: what is it, and what is special about it? *Cognition* 100, 33–72. doi: 10.1016/j.cognition.2005.11.005

James, I. (2010). "Autism and art," in *Neurological Disorders in Famous Artists-Part 3*, ed. J. Bogousslavsky (Basel: Karger Publishers).

Jones, M. N., and Mewhort, D. J. K. (2007). Representing word meaning and order information in a composite holographic lexicon. *Psychol. Rev.* 114, 1–37. doi: 10.1037/0033-295x.114.1.1

Jusczyk, P. W. (1999). How infants begin to extract words from speech. *Trends Cogn. Sci.* 3, 323–328. doi: 10.1016/s1364-6613(99)01363-7

Just, M. A., Cherkassky, V. L., Keller, T. A., and Minshew, N. J. (2004). Cortical activation and synchronisation during sentence comprehension in high-functioning autism: evidence of underconnectivity. *Brain* 127, 1811–1821. doi: 10.1093/brain/awh199

Kagan, J. (1972). Motives and development. *J. Pers. Soc. Psychol.* 22, 51–66.

Kiebel, S. J., Daunizeau, J., and Friston, K. J. (2008). A hierarchy of time scales and the brain. *PLoS Comput. Biol.* 4:e1000209. doi: 10.1371/journal.pcbi.1000209

Kleinmintz, O. M. (2017). "Train yourself to let go: the benefits of deliberate practice on creativity and its neural basis," in *Exploring the Benefits of Creativity in Education, Media, and Arts (pp. 67-90) Pennsylvania*, ed. N. R. Silton (IGI Global).

Kleinmintz, O. M., Ivancovsky, T., and Shamay-Tsoory, S. G. (2019). The two-fold model of creativity: the neural underpinnings of the generation and evaluation of creative ideas. *Curr. Opin. Behav. Sci.* 27, 131–138. doi: 10.1016/j.cobeha.2018.11.004

Klimesch, W. (2012). α-Band oscillations, attention, and controlled access to stored information. *Trends Cogn. Sci.* 16, 606–617. doi: 10.1016/j.tics.2012.10.007

Kóbor, A., Takács, Á, Kardos, Z., Janacsek, K., Horváth, K., and Csépe, V. (2018). ERPs differentiate sensitivity to statistical probabilities and the learning of sequential structures during procedural learning. *Biol. Psychol.* 135, 180–193. doi: 10.1016/j.biopsycho.2018.04.001

Koelsch, S. (2014). Brain correlates of music-evoked emotions. *Nat. Rev. Neurosci.* 15, 170–180. doi: 10.1038/nrn3666

Koelsch, S., Busch, T., Jentschke, S., and Rohrmeier, M. (2016). Under the hood of statistical learning: a statistical MMN reflects the magnitude of transitional probabilities in auditory sequences. *Sci. Rep.* 6, 1–11.

Kouneiher, F., Charron, S., and Koechlin, E. (2009). Motivation and cognitive control in the human prefrontal cortex. *Nat. Neurosci.* 12:939. doi: 10.1038/nn.2321

Kozbelt, A., Beghetto, R. A., and Runco, M. A. (2010). "Theories of creativity," in *The Cambridge Handbook of Creativity*, eds J. C. Kaufman and R. J. Sternberg (New York: Cambridge University Press), 20–47.

Lanillos, P., Oliva, D., Philippsen, A., Yamashita, Y., Nagai, Y., and Cheng, G. (2020). A review of neural network models of schizophrenia and autism spectrum disorders. *Neural Netw.* 122, 338–363. doi: 10.1016/j.neunet.2019.10.014

Lawson, R. P., Rees, G., and Friston, K. J. (2014). Aberrant precision account for autism. *Front. Hum. Neurosci.* 8:302.

Limb, C. J., and Braun, A. R. (2008). Neural Substrates of spontaneous musical performance: an fMRI study of Jazz improvisation. *PLoS One* 3:e1679. doi: 10.1371/journal.pone.0001679

Lepistö, T., Kujala, T., Vanhala, R., Alku, P., Huotilainen, M., and Näätänen, R. (2005). The discrimination of and orienting to speech and non-speech sounds in children with autism. *Brain Res.* 1066, 147–157. doi: 10.1016/j.brainres.2005.10.052

Liu, S., Erkkinen, M. G., Healey, M. L., Xu, Y., Swett, K. E., Chow, H. M., et al. (2015). Brain activity and connectivity during poetry composition: toward a multidimensional model of the creative process. *Hum. Brain Mapp.* 36, 3351–3372. doi: 10.1002/hbm.22849

Liu, Z., Zhang, J., Xie, X., Rolls, E. T., Sun, J., Zhang, K., et al. (2018). Neural and genetic determinants of creativity. *NeuroImage* 174, 164–176. doi: 10.1016/j.neuroimage.2018.02.067

Lopata, J. A., Nowicki, E. A., and Joanisse, M. F. (2017). Creativity as a distinct trainable mental state: an EEG study of musical improvisation. *Neuropsychologia* 99, 246–258. doi: 10.1016/j.neuropsychologia.2017.03.020

Lu, K., and Vicario, D. S. (2014). Statistical learning of recurring sound patterns encodes auditory objects in songbird forebrain. *Proc. Natl. Acad. Sci.* 111, 14553–14558. doi: 10.1073/pnas.1412109111

Lu, K., and Vicario, D. S. (2017). Familiar but unexpected : effects of sound context statistics on auditory responses in the songbird forebrain. *J. Neurosci.* 37, 12006–12017.

Lubart, T. I., and Mouchiroud, C. (2003). "Creativity: a source of difficulty in problem-solving," in *Psychology of Problem Solving*, eds J. E. Davidson and R. J. Sternberg (New York: Cambridge University Press), 127–148. doi: 10.1017/cbo9780511615771.005

Lustenberger, C., Boyle, M. R., Foulser, A. A., Mellin, J. M., and Fröhlich, F. (2015). Functional role of frontal alpha oscillations in creativity. *Cortex* 67, 74–82. doi: 10.1016/j.cortex.2015.03.012

Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., and Macrae, C. N. (2007). Wandering minds: default network and stimulus-independent thought. *Science* 315, 393–395. doi: 10.1126/science.1131295

Mason, R. A., Williams, D. L., Kana, R. K., Minshew, N., and Just, M. A. (2008). Theory of mind disruption and recruitment of the right hemisphere during narrative comprehension in autism. *Neuropsychologia* 46, 269–280. doi: 10.1016/j.neuropsychologia.2007.07.018

Meda, S. A., Ruaño, G., Windemuth, A., O'Neil, K., Berwise, C., Dunn, S. M., et al. (2014). Multivariate analysis revealed genetic associations of the resting default mode network in patients with psychotic bipolar disorder and schizophrenia. *Proc. Natl. Acad. Sci. U.S.A.* 111, E2066–E2075.

Meyer, L. B. (2008). *Emotion and Meaning in Music*. Chicago: University of Chicago Press.

Moser, J., Batterink, L., Hegner, Y. L., Schleger, F., Braun, C., Paller, K. A., et al. (2020). Dynamics of nonlinguistic statistical learning: from neural entrainment to the emergence of explicit knowledge. *BioRxiv [preprint]* doi: 10.1101/2020.07.30.228130

Mumford, D. (1992). The role of cortico-cortical loops in the computational architecture of the neocortex - II. *Biol. Cybern* 66, 241–251. doi: 10.1007/bf00198477

Nagai, Y. (2019). Predictive learning: its key role in early cognitive development. *Philos. Trans. R. Soc. B Biol. Sci.* 374:20180030. doi: 10.1098/rstb.2018.0030

O'Riordan, M. A., Plaisted, K. C., Driver, J., and Baron-Cohen, S. (2001). Superior visual search for autism. *J. Exp. Psychol. Hum. Perc. Perform.* 27, 719–730.

Padmanabhan, A., Lynch, C. J., Schaer, M., and Menon, V. (2017). Default mode network in autism. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 2, 476–486.

Paraskevopoulos, E., Kuchenbuch, A., Herholz, S. C., and Pantev, C. (2012). Statistical learning effects in musicians and non-musicians: an MEG study. *Neuropsychologia* 50, 341–349. doi: 10.1016/j.neuropsychologia.2011.12.007

Park, H., Thut, G., and Gross, J. (2018). Predictive entrainment of natural speech through two fronto-motor top-down channels. *BioRxiv [Preprint]* doi: 10.1101/280032

Pearce, M. T., and Wiggins, G. A. (2012). Auditory expectation: the information dynamics of music perception and cognition. *Top. Cogn. Sci.* 4, 625–652. doi: 10.1111/j.1756-8765.2012.01214.x

Pearce, M. T., Müllensiefen, D., and Wiggins, G. A. (2010). The role of expectation and probabilistic learning in auditory boundary perception: a model comparison. *Perception* 39, 1367–1391. doi: 10.1068/p6507

Pearce, M., and Wiggins, G. A. (2006). Expectation in melody: the influence of context and learning. *Music Perception* 23, 377–405. doi: 10.1525/mp.2006.23.5.377

Pellicano, E., and Burr, D. (2012). When the world becomes 'too real': a Bayesian explanation of autistic perception. *Trends Cogn. Sci.* 16, 504–510. doi: 10.1016/j.tics.2012.08.009

Perruchet, P., and Pacton, S. (2006). Implicit learning and statistical learning: one phenomenon two approaches. *Trends Cogn. Sci.* 10, 233–238. doi: 10.1016/j.tics.2006.03.006

Philippsen, A., and Nagai, Y. (2019). "Predictive coding model of representational drawings in human children and chimpanzees," in *Proceedings of the 2019 Joint IEEE 9th International Conference on Development and Learning and Epigenetic Robotics (ICDL-EpiRob)*, (Piscataway, NJ: IEEE).

Pinho, A. L., Ullén, F., Castelo-Branco, M., Fransson, P., and de Manzano, Ö (2015). Addressing a paradox: dual strategies for creative performance in introspective and introspective networks. *Cereb. Cortex* 26, 3052–3063. doi: 10.1093/cercor/bhv130

Przysinda, E., Zeng, T., Maves, K., Arkin, C., and Loui, P. (2017). Jazz musicians reveal the role of expectancy in human creativity. *Brain Cogn.* 119, 45–53. doi: 10.1016/j.bandc.2017.09.008

Rao, R. P. N., and Ballard, D. H. (1999). Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects. *Nat. Neurosci.* 2:79. doi: 10.1038/4580

Robert, J. S. (2011). *"Creativity". Cognitive Psychology*, 6 Edn. Belmont, CA: Cengage Learning, 479.

Rogers, T. T., and McClelland, J. L. J. (2004). *Semantic Cognition: a Parallel-Distributed Processing Approach*. Cambridge: MIT Press.

Roser, M. E., Aslin, R. N., McKenzie, R., Zahra, D., and Fiser, J. (2015). Enhanced visual statistical learning in adults with autism. *Neuropsychology* 29:163. doi: 10.1037/neu0000137

Saffran, J. R. (2018). Statistical learning as a window into developmental disabilities. *J. Neurodev. Disord.* 10:35.

Saffran, J. R., Aslin, R. N., and Newport, E. L. (1996). Statistical learning in 8-month-old infants. *Science* 274, 1926–1928. doi: 10.1126/science.274.5294.1926

Saffran, J. R., Hauser, M., Seibel, R., Kapfhamer, J., Tsao, F., and Cushman, F. (2008). Grammatical pattern learning in human infants and cotton-top tamarin monkeys. *Cognition* 107, 479–500. doi: 10.1016/j.cognition.2007.10.010

Schenker, H., and Jonas, O. (1956). *Neue Musikalische Theorien und Phantasien*. Leipzig: Universal Edition.

Schmidhuber, J. (2006). Developmental robotics, optimal artificial curiosity, creativity, music, and fine arts. *Connection Sci.* 18, 173–187. doi: 10.1080/09540090600768658

Seither-Preisler, A., Parncutt, R., and Schneider, P. (2014). Size and synchronisation of the auditory cortex promote musical, literacy, and attentional skills in children. *J. Neurosci.* 34, 10937–10949. doi: 10.1523/jneurosci.5315-13.2014

Seri, S., Cerquiglini, A., Pisani, F., and Curatolo, P. (1999). Autism in tuberous sclerosis: evoked potential evidence for a deficit in auditory sensory processing. *Clin. Neurophysiol.* 110, 1825–1830. doi: 10.1016/S1388-2457(99)00137-6

Shannon, C. E. (1948). Mathematical theory of communication. *Bell Tech. J.* 27, 623–656.

Sinha, P., Kjelgaard, M. M., Gandhi, T. K., Tsourides, K., Cardinaux, A. L., Pantazis, D., et al. (2014). Autism as a disorder of prediction. *Proc. Natl. Acad. Sci. U.S.A.* 111, 15220–15225.

Sloboda, J. A. (1991). Music structure and emotional response: some empirical findings. *Psychol. Music* 19, 110–120. doi: 10.1177/0305735691192002

Sloutsky, V. M. (2010). From perceptual categories to concepts: what develops? *Cogn. Sci.* 34, 1244–1286. doi: 10.1111/j.1551-6709.2010.01129.x

Soon, C. S., Brass, M., Heinze, H.-J., and Haynes, J.-D. (2008). Unconscious determinants of free decisions in the human brain. *Nat. Neurosci.* 11:543. doi: 10.1038/nn.2112

Taylor, V. A., Daneault, V., Grant, J., Scavone, G., Breton, E., Roffe-Vidal, S., et al. (2013). Impact of meditation training on the default mode network during a restful state. *Soc. Cogn. Affective Neurosci.* 8, 4–14. doi: 10.1093/scan/nsr087

Teinonen, T., Fellman, V., Näätänen, R., Alku, P., and Huotilainen, M. (2009). Statistical language learning in neonates revealed by event-related brain potentials. *BMC Neurosci.* 10:21.

Thiessen, E. D., Kronstein, A. T., and Hufnagle, D. G. (2013). The extraction and integration framework : a two-process account of statistical learning. *Psychol. Bull.* 139, 792–814.

Toro, J. M., Sinnett, S., and Soto-Faraco, S. (2005). Speech segmentation using statistical learning depends on the attention. *Cognition* 97, 25–34.

Tsogli, V., Jentschke, S., Daikoku, T., and Koelsch, S. (2019). When the statistical MMN meets the physical MMN. *Sci. Rep.* 9, 1–12.

Van de Cruys, S., and Wagemans, J. (2011). Putting rewards in art: a tentative prediction error accounts for visual art. *I-Perception* 2, 1035–1062. doi: 10.1068/i0466aap

Van de Cruys, S., Evers, K., Van der Hallen, R., Van Eylen, L., Boets, B., de-Wit, L., et al. (2014). Precise minds in uncertain worlds: predictive coding in autism. *Psychol. Rev.* 121, 649–675. doi: 10.1037/a0037665

Wiggins, G. A. (2012). The mind's chorus: creativity before consciousness. *Cogn. Comput.* 4, 306–319.

Wiggins, G. A. (2020). Creativity, information, and consciousness: the information dynamics of thinking. *Physics Life Rev.* 35, 1–39. doi: 10.1016/j.plrev.2018.05.001

Wiggins, G. A., and Sanjekdar, A. (2019). Learning and consolidation as rerepresentation: revising the meaning of memory. *Front. Psychol.* 10:802.

Zabelina, D. L., and Andrews-Hanna, J. R. (2016). Dynamic network interactions supporting internally oriented cognition. *Curr. Opin. Neurobiol.* 40, 86–93. doi: 10.1016/j.conb.2016.06.014

Zatorre, R. J., Belin, P., and Penhune, V. B. (2002). Structure and function of the auditory cortex: music and speech. *Trends Cogn. Sci.* 6, 37–46. doi: 10.1016/s1364-6613(00)01816-7

Zioga, I., Harrison, P. M. C., Pearce, M. T., Bhattacharya, J., Di Bernardi, and Luft, C. (2019). From learning to creativity: identifying the behavioural and neural correlates of learning to predict human judgements of musical creativity. *NeuroImage* 206:116311. doi: 10.1016/j.neuroimage.2019.116311

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HYPOTHESIS AND THEORY
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Creativity Is Optimal Novelty and Maximal Positive Affect: A New Definition Based on the Spreading Activation Model

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Creativity is commonly defined as a process that leads to a novel and useful outcome (an idea, product, or expression). However, two dilemmas about this definition remain unresolved: (1) A strict application of usefulness is difficult to apply to artistic works: who decides what artwork is useful, and how it is useful? (2) The implied boundary conditions of novelty are problematic: The default perspective is that novelty has a monotonic increasing relationship with creativity, or it is categorical—i.e., novel or not. To address these dilemmas, this paper proposes a spreading activation model of creativity (SAMOC), a model built on a brain-architecture-inspired vast interconnected network of nodes, each node representing information, and assigned meanings through interaction with the environment. Nodes are linked to each other according to principles of temporal contiguity (linking objects/events in time) and similarity (linking objects/events by shared features). A node activated by attention spreads through the network through previously linked nodes. Nodes that are well connected activate each other easily, while those that are weakly connected do not. Net total activation corresponds to positive affect (e.g., pleasure), and this is proposed as an essential criteria for a creative work of art, instead of usefulness. SAMOC also predicts that creativity will be optimized at an intermediate, not extreme, level of novelty. Too much activation will occur with the activation of preexisting ideas (hence reproduction rather than creativity), and too much novelty will not produce spread of activation. The two functions (spreading activation and the novelty curve) are superposed to demonstrate this optimal novelty hypothesis. Early evidence of the hypothesis comes from the data that some great works of art were critically rejected at premiers (suggesting excessive novelty), but after sufficient repetition (and therefore linking) became suitably associated and commenced generating activation. The hypothesis has important implications for future empirical research programs on creativity, and for the definition of creativity itself.

Keywords: creativity, novelty, aesthetic experience, spreading activation, mirroring, pleasure, usefulness, cognitive musicology

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INTRODUCTION

Creativity is a process that, from Western perspectives in particular, leads to the production of a novel, useful idea or product (Runco and Jaeger, 2012) and is distinct from reproduction or non-production. It can be broadly conceptualized as consisting of four components: (1) ability (to create), (2) intentionality (to create), (3) a context in which the creativity occurs, and (4) a product is generated that is novel and useful (Walia, 2019; see also Amabile and Pratt, 2016).

Problem solving frequently occupies creativity research investigations. Problem solving that requires a creative solution is quite broad and can be classified as well-defined and as ill-defined (Wu et al., 2017). Well-defined problems have clearly stated goals, such as solving a complicated mathematical equation in a new way or building a bridge over a very long stretch of water. Assessing the usefulness of such tasks is relatively easy, but novelty less so, leading to debate over whether solutions to well-defined problems in fact exhibit overlap between creativity and intelligence, and not exclusively creativity (Kaufmann, 2003; Pétervári et al., 2016). Ill-defined problems require inexact solutions, for example "compose a new piece of music that is 20 min long" or "paint something that moves me," making them more aligned with conventional conceptions of creativity (Reitman, 1965; Pétervári et al., 2016). As we shall see, defining the process of solving ill-defined problems and assessing them according to the criteria of usefulness and novelty raise questions that are yet to be resolved.

One of the reasons for the impasse stems from the need for testable theory. This paper, therefore, builds on existing models that make explicit, testable predictions about artistic creativity and aim to explain all creativity for the case of ill-defined problems, with the main focus of this paper on the arts, and honing in on examples from music practice and scholarship in particular. Furthermore, rather than building a model around data on creativity, a general model of mental processing is proposed, building on the work of Martindale and Gabora in particular (Martindale, 1995, 1999; Gabora, 2007, 2010, 2016; Vartanian et al., 2003, 2007; DiPaola and Gabora, 2009; Ranjan and Gabora, 2013), which are based on principles of connectionism. This model will be applied to explain data and build hypotheses about creativity.

The paper commences by laying out the connectionist framework from which a spreading activation model is presented. Then, creativity will be modeled, as will aesthetic experience, since the two have important cognitive overlaps that will assist in building a hypothesis. Once these phenomena are modeled, attention will be turned to resolving the dilemmas of novelty and usefulness. The paper then presents evidence for the model and the adequacy of the revised definition.

SPREADING ACTIVATION MODEL

Connectionist frameworks consist of two simple components: nodes and links. "Nodes" encode, store, process, and recall simple pieces of information in a massively interconnected network. The nodes can be referred to as "cognitive units," mental representations, or schemata, or as the same label as the anatomical source of the analogy—neuron. For the purpose of the present discussion, a simple piece of information will be an object (e.g., a chair, a painting) or an event (a piece of music, dinner), or some component of each. The interconnection of these nodes is achieved by the second component, referred to as a weight or link, analogous to neurophysiological synapses. They link nodes together to different degrees. The linking process takes place through two main mechanisms—temporal contiguity and feature similarity.

Temporal contiguity refers to the coding of objects/events in the environment that occur in close succession. Such pairing will lead to the priming (small amount of activation) of the second object/event while the first object/event is the focus of attention. As a simple example, a bar of music in a familiar piece might be represented by one node, which then primes the next bar, and if the next bar is heard, the representation of that bar becomes activated (that is, with additional activation). **Figure 1** provides an example of a network where three extracts of music are represented. The sequence of each piece is retained in memory (as indicated by the arrows connecting one bar to the next), but feature similarity means that if a fragment of incoming music is sufficiently similar to an existing fragment (or node—shown as an oval), even if from another piece of music, the node representing that fragment will be recruited, rather than a new node representing the same features duplicating the representation (a process referred to as 'veridical chaining' Schubert, 2015; Schubert and Pearce, 2015).

Furthermore, when a node is activated, nodes to which it has been previously paired will themselves be primed (i.e., coming close to activation), or activated, depending on the weighting of the links, and depending on whether other nodes are themselves also activating or priming those nodes. This mechanism of node activation may occur in the form of a transmitter substance (analogous to a neurotransmitter), or as a succession of brief stimulations, referred to as "firing," where the rate of firing is indicative of strength of transmission. The method of transmission is not of particular concern here as the current application is conceptual rather than biological or mathematical (but for further information, see Smolensky, 1988).

The model presented here necessitates considerable simplification. If we drill down into the node representation of an object/event or part thereof, the node is usually itself interconnected with a "basic feature" node which gives rise to the representation, such as those representing only line angles, color, shape, motion, basic auditory pitch, and so forth. These fundamental building blocks of perception are referred to in some network models of memory as microfeatures (Churchland, 1992; Ranjan and Gabora, 2013) and can also be represented as a more detailed part of the network in the model proposed here but has been omitted for ease of visualizing. While the ensuing discussion treats nodes as representing objects, events, concepts, and so forth, what they reference from the real world need not be fixed for the purpose of the argument being built and will typically be referred to as representations of objects/events or parts thereof, again for convenience and simplicity. Moreover,

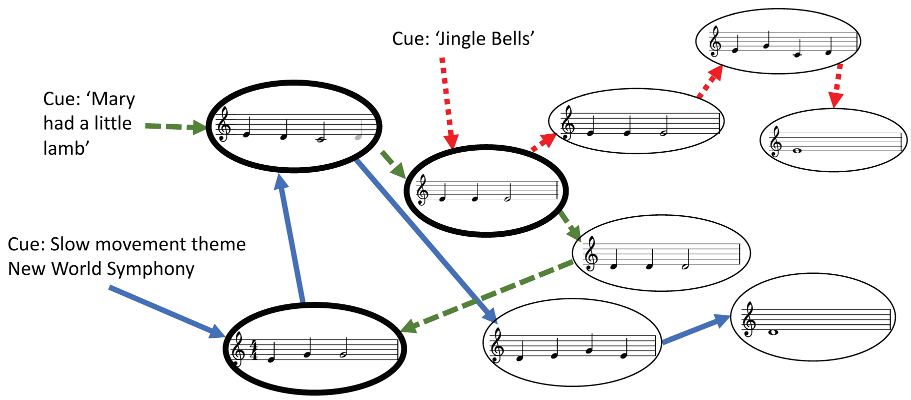

FIGURE 1 | Illustration of veridical chaining, showing music fragments (rhythmically simplified and transposed to C major) parsed into nodes (shown as ovals) and combined through a chaining process. Arrows indicate the chaining links at each temporal step (each color/pattern arrow represents a step in one of the three pieces of music). That is, when the first arrow, cued by the name of the piece of music, activates its target node, the arrow exiting that node primes the next node until the current node has played, and so on. Thick oval nodes indicate those that have been reused in the examples shown.

the extent of activation spread through a network is not determined solely by the weighting of links but also by a concept referred to as temperature (for more details, see Gabora, 2010), where a "high temperature" sets the network up for overall higher connectivity potential—and hence more distant concepts can be more easily activated by than at so-called cold temperature. The principle of network temperature will also be put aside in the present account. Moreover, another simplification is that we will not be considering a special type of link that operates in reverse to the transmission of activation, namely, those "links" that block activation. These "inhibitory links" play an important role in cognition and creativity (Martindale, 1984, 1995; Gabora, 2000, 2016) but will also be put to the side here to facilitate clarity, except to say that they reduce the amount of activation in the network, rather than add to it.

With this spreading activation model, various mental organization phenomena can be illustrated. For example, feather, beak, flight, eyes, and tongue (whether the graphemes, spoken words, images, or multisensory sensation) will each prime a (general) mental representation (or "schema" or "prototype") of the node representing a bird, as well as activating the nodes representing each of the aforementioned body parts. This collection of related concepts can be illustrated in a network as a number of individual nodes that are strongly linked, using a single color combination of nodes, as in **Figure 2** where nodes are shown as small circles in the mental networks of three hypothetical people (persons i, ii, and iii) over two points in time (time A and time B). This form of illustration is based on graph theory, used to understand complex, dynamic, adaptive systems (Gros, 2015). Node representations emerge from exposure to the environment from a theoretically "blank" network, depicted by white circles in the background of **Figure 2** (we will mainly focus on the network for person i at time A for now). Wheels, doors, boot, steering wheel, bumper bar, and engine will prime the general mental representation of a car, another group of nodes but of a single, different color in **Figure 2** to those represented by the concept of a bird. The two clusters of features are each related to themselves, but distinct from the other (bird and car), and so the links between the concept of a bird and a car are weak. And so in **Figure 2**, they will occupy two color clusters that are not directly adjacent to one another. However, if a bird and a car are experienced according to one or more of the linking principles, the connections will adjust. For example, the dark blue nodes (in the middle of the illustrated network) may represent the concept of car, and the gray nodes (at the top left) represent the concept of bird. Frequent temporal contiguity of the two concepts can create and increase the direct link strength between the two clusters of nodes (indicated by the line joining the dark blue and gray node clusters in **Figure 2iA**). As will be explained below, the linking of two *never-before linked* concept or object/event representations (node clusters) is referred to as "transcombination" and is central to the explanation of creativity that will be put forward. This basic architecture will be used to develop a spreading activation model of creativity (SAMOC).

Spreading activation models have been promising in their capacity to replicate human behaviors, such as forgetting and confusing, as well as remembering. Furthermore, a good deal of data support a spreading activation explanation of creativity (Langley and Jones, 1988; Martindale, 1995; Schooler, 1999; Friedman et al., 2003; Sio and Rudowicz, 2007; Cai et al., 2009; Beaty and Silvia, 2012; Gilhooly et al., 2015; Weisberg, 2015; Gilhooly, 2016). Gabora (2010, p. 6) argued that "memory is distributed and content addressable [and this] is critically important for creativity." By this, Gabora means that memory is not only represented by nodes but that there are overlapping (multiple) pathways to activating nodes, an architecture highly conducive to solving problems in different (including creative) ways—a central advantage of such a mental architecture (see also Gabora, 2002). That is, this mental architecture facilitates "retrieval routes for creatively forging relationships between what is currently experienced and what has been experienced in the past" (Gabora, 2010, p. 6). The spreading activation model applied here is based on the approach proposed by

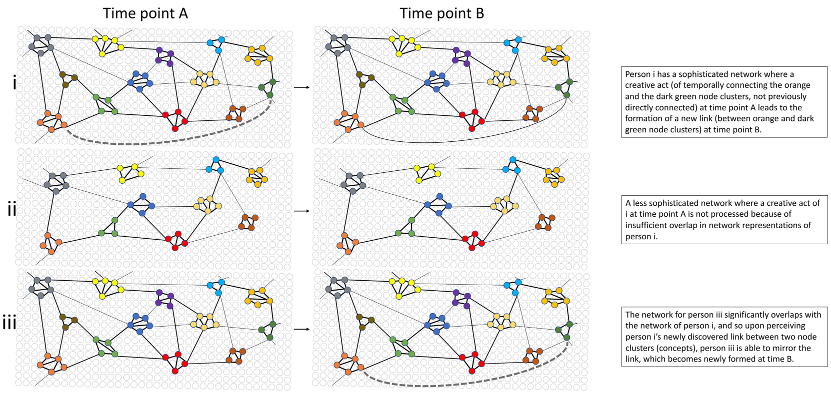

FIGURE 2 | Network representations for three people at two points in time (one time point per column), illustrating the spreading activation model of creativity (SAMOC). It shows clusters of nodes organized into coherent sematic and sequential encoding of objects/events and thoughts, with single colors of closely packed nodes (node clusters) representing a coherent concept, object, or event, and lines between nodes indicating the link strength, with thicker lines indicating stronger links, and therefore a greater propensity to prime or activate an adjacent node, which then spreads through the network according to the weightings of links to adjacent nodes. The dotted line indicates the formation of a new connection between existing node clusters ("transcombination"), either as a result of creative thought or through perception of the newly combined concepts, objects, or events. **(i)** depicts the network for a person who has just made a novel link between two never-before combined ideas (the concepts/objects/events represented by the orange and the dark green node clusters), and so a new link is forming [dotted line in network (iA)]. Over time, the repeated thought or exposure to the new combination strengthens the link between the node clusters (time point B). The new link can be formed through an intermediate node, or directly between the node clusters (the latter shown in the illustration for simplicity). The network for person **(ii)** indicates that this person only shares a small number of concepts that person **(i)** has, and so is unable to process the creative, new link achieved by person **(i)**. At time B person **(ii)** has had no noticeable change in their network, and so will not experience additional activation as a result of being exposed to the newly combined ideas, leading to a non-positive affect experience. Person **(iii)** on the other hand has considerable overlap in mental representations with person **(i)** and so is also able to form a connection between the newly combined clusters (orange and dark green), with the newly forming links appearing at time point B, mirroring that experience by person **(i)** at time point A, and leading to additional activation which generates positive affect (pleasure). The experience for person **(i)** and person **(iii)** is considered creative because previously unlinked nodes have been combined for the first time and generate positive affect. Furthermore, the existing pathways prior to their being combined was relatively distant in terms of the number of nodes that needed to be traversed, and the net, effective link strength. Hence, the greater the separation between nodes (or node clusters) in terms of intermediate nodes and low net link strength, the greater the perception of novelty. There are of course several pathways through which one node can be connected to another distant node in the network, and this is characteristic of the complex dynamic creative system being proposed.

Howes and O'Shea (2014) and incorporates other influences, in particular Martindale (1984) and Thagard and Stewart (2011).

CREATIVITY AS COMBINATION

Creativity researchers predominantly agree that creativity does not take place in a mental vacuum. Even if creative insight may appear to the observer, and even to the creator, as coming out of nowhere, considerable evidence suggests that creativity must involve a combination of existing ideas but, combined in ways that are original and (in the case of some definitions of creativity), solves a problem (Mednick, 1962; Boden, 1994; Baer, 2016). This understanding of the creative mechanism has been discussed in the past in terms of "recombination" (Welch, 1946). Influentially, Boden (2004) proposed two broad forms of creativity that hinge on the combination of existing or newly formed concepts: exploratory and transformational. Exploratory forms of creativity, according to Boden, consist of (re)combination within the same "conceptual space," such as a creative set of chess moves (from the large but limited set of possibilities bounded by the conceptual space of the rules of chess) or a creative piece of tonal music (bounded by the rules of tonal music, but involving a massive range of possible pitch combinations). Exploratory forms of creativity operate more or less within a single conceptual space. Transformational forms of creativity, on the other hand, take place when novel combinations are made across two or more different conceptual spaces and usually lead to a novel idea that could not have been thought of before. These different forms of representation combinations have inspired mathematical frameworks for implementing creativity in artificial intelligence (Wiggins, 2006). The key point here is that never-before combined nodes are a necessary part of creative processing. This raises a problem of terminology to which we shall briefly turn our attention.

TRANSCOMBINATION—COMBINING NEVER BEFORE COMBINED IDEAS (NODES)

The term "combination" does not adequately capture the mental process of creativity. Combination, from a mathematical perspective, means reordering items in an array in any way, whereas in creativity combining necessarily refers to the smaller set of reordering that consists only of those possibilities that are *new* combinations. "Recombination" could be construed as putting back pieces as they originally were, hence not creative, but reproduction. Furthermore, exploratory and transformational forms of creativity encompass such a wide domain of possible conceptual nodes that "combination" is both inadequate and non-specific. Therefore, I will use the term "transcombination."

'Transcombination' draws attention to the novelty of combinations that take place within a conceptual space (exploratory form of creativity) but also more aptly describes the transformational form of new combinations. That is, the suffix "*trans*" makes clear that the two ideas being combined have not been combined together in such a way before. For those accustomed to much of the existing literature on creativity, the term has the same meaning as "combination" or as "recombination" (depending on the source) and avoids the need for the clumsy grapheme "(re)combination."

Another possible term to adopt for this meaning is convolution, as proposed by Thagard and Stewart (2011), but that term has a particular mathematical connotation and specifically refers to an intertwining of mental representations that is proposed as a process distinct from synchronization, rather than a fresh combination of nodes/concepts. The current paper is agnostic about whether "combination" of nodes occur as a result of synchronization (from which comes the adage "neurons that fire together wire together," after Hebb, 1949) or as a result of convolution. And so the neologism "transcombination" is the catch-all term for the first time a new combination of nodes have been directly linked to each other.

UNCONSCIOUS TRANSCOMBINATIONS

Because creativity involves intuitive thought processes, meaning that the individual in the act of creating does not need direct conscious access to the creative process [a process frequently referred to as incubation – see Sio and Rudowicz (2007) and Gilhooly (2016)], some views about transcombination are more metaphysical and are not in any obvious way compatible with the combination of existing ideas account. Lavazza and Manzotti (2013) proposed that transcombination alone is insufficient for describing the creative process. The creative act, they argue, must reach outside the set of existing patterns, symbols, and concepts, into an orthogonal dimension that extends existing semantic space. Semantic space, here, can be taken to be an analog of Boden's concept space. However, Lavazza and Manzotti proposed that this extension is into the environment itself, leaning on William James' concept of the mental "fringe." While the finer detail of this argument is beyond the scope of the present undertaking, it is a necessary part of the story because it suggests that transcombination alone is insufficient to explain creativity and that something extra is needed. However, given that this metaphysical treatment of the problem is reliant on conceptual structures that are non-accessible to the individual (Jacoby and Witherspoon, 1982), the additional dimension may still be explicable in the spreading activation model, specifically coming under the transformational form of creativity proposed by Boden, where different conceptual spaces can coexist in cognition. As Simonton put it, "[t]he magic behind the sudden, unexpected, and seemingly unprepared inspiration has now been replaced by the lawful operation of subliminal stimulation and spreading activation." (Simonton, 2000, p. 152).

The driving principle of transcombination is not that new concepts/ideas are formed but rather that existing concepts/ideas are combined in a novel fashion. An example of this is the artificial intelligence treatment of music composition by Cope (2001, 2006). His experiments in music intelligence are built on the idea that music of a particular style can be broken into its components, separated, and then newly combined to produce original sounding pieces that are still within the style of the original. For example, by parsing Chopin's piano composition repertoire into small components—let us call the component nodes—they can be recombined (actually, transcombined) within a given musical framework (such as an existing piece by Chopin, but stripped of its musical surface) to produce new sounding works that are stylistically identifiable as Chopin, without the listener being able to detect that old material is being combined (or recycled) in new ways.

The argument by Lavazza and Manzotti (2013), that to be truly creative one must reach out beyond the confines of existing conceptual space, can be dealt with by proposing that the "reaching" may simply take place into existing, but consciously inaccessible nodes. In a discussion of Cope's EMI system Dennett (2001; see also Mills et al., 2018) referred to combination (here, transcombination) as being comparable to walking into a messy room and discovering things that trigger a new solution to a problem. The messy room, in the present framework, is a collection of nodes that exists below consciousness but are accessible during periods of (possibly unconscious) creative incubation (for a more recent explanation of creative idea generation that is also highly compatible with the spreading activation account, see Gabora, 2016). And so even if one must seek inspiration from outside the consciously accessible nodes, transcombination can, and probably does, still come from existing mental representations.

In the SAMOC spreading activation model, consider, then, a number of distinct, weakly linked networks of nodes, each node representing a range of previously associated objects/events (see, for example, the visual representation in **Figure 2iA** as discussed above). During the creative process where a problem requires a novel solution, the solution is achieved by an "intersection of paths of spreading activation" (Schooler, 1999, p. 353) from these previously weakly or unlinked node clusters. To illustrate this, in **Figure 2iA** a cluster of nodes (circles) with the same color have been previously linked because they represent a reasonably coherent concept. That is, the link strength is generally stronger between nodes within a particular (single colored) cluster than are links across adjacent clusters of nodes. However, note, too, that most of the (like colored) clusters can indirectly be connected to any other cluster. However, the likelihood of this occurring diminishes based on the number of intermediate nodes that separate them, and the net link strength of that pathway (keeping in mind that there are alternate pathways in this complex, dynamic system). In the case of Cope's experiments in musical intelligence, each of the Chopin fragments can be viewed as occupying a node cluster in **Figure 2iA** and that non adjacent clusters were being transcombined to create a satisfying, apparently novel Chopin composition.

EXAMPLES FROM WESTERN MUSIC HISTORY

In Western art music composition from around 1650 to 1800, theory was built on the idea that musical harmonic progressions should move from tension to release, with sophisticated rules of harmony and voice leading driving how to set up a harmonic dissonance and how that dissonance should then be resolved (Rameau, 1722/1971; Aldwell, 1989). Variants of these rules would appear throughout this period. These variants are exploratory forms of creativity. However, the general idea that a harmony did not need to be resolved according to the established tension-release principles in Western art music did not occur, in general (although there were exceptions), to composers until the mid nineteenth century when Eastern ways of thinking started to bear influence on philosophers such as Schopenhauer, and in composers such as Wagner in particular, who was himself influenced by Schopenhauer (Wagner, 1987, p. 323). That is, combining Schopenhauer's ideas with resolution of harmony produced a translational form of creative transcombination. Wagner's idea of delaying the resolution of dissonance was revolutionary. Another example was the translational extension of this idea in the early twentieth century, with the rejection of the tension and release script altogether, replaced by the "emancipation of dissonance" (Schoenberg, 1950, p. 48) in music compositions. This change culminated in dodecaphonic (12 tone) technique of the second Viennese school, where instead of following the rules of tension release where particular notes were favored over others, all 12 tones of the scale would be treated as equal, which to the ears of people lacking familiarity with the system would mostly sound like dissonances moving to dissonances, tension to tension, a disturbing, translational development in musical ideas, a development that is doubtless as controversial as it is creative—a point to which we shall return.

As another example, John Cage's reading of Eastern philosophy, which informed his interest in removing determinism and ego from music (Kahn, 1997, p. 559), led to the unlikely (again, transformational) transcombination of ideas of a piece of music consisting of a musician sitting at a musical instrument and remaining silent for the entire performance, as was the case for the piece titled 4′33″. The composer and the performer had their ego removed from the musical process and allowed the "music" to "just be itself" by being the sounds in the environment. Cage reflected on his compositional approaches—"I do not wish blamed on Zen, though without my engagement with Zen [. . .] I doubt whether I would have done what I have done." (Cage, 1961/2011, p. xxxi). The idea of a delayed and then abandoned resolution was once again pushed forward with the idea of music as (unobtainable) silence, ideas that are still quite surprising to those immersed in the tonal music traditions of per-twentieth century Western Art music and in popular music of the 20th and 21st centuries. However, a close examination of these creative processes can be traced to a novel combination of existing ideas. Furthermore, these transcombinations can occur in many ways and at many levels. As another example, in jazz forms Gatherer (1997) suggested that particular styles of music emerged from new combinations of preexisting styles, such as Bebop emerging from a transcombination of Swing and Blues-oriented Jump style (p. 78).

However, how do we know if these new works are creative? Novelty can be explained by the inverse of link strength between node clusters. Usefulness is more difficult to explain. To understand the dilemma of usefulness as a criterion of artistic creativity, we need to examine the spreading activation model as it applies to the *perception* of an artistic work, namely, "aesthetic experience."

AESTHETIC EXPERIENCE

Aesthetic experience in Western cultures is concerned with the reception of a created product and involves contemplation of, or engagement with, that product. A conventional definition of aesthetic experience is that it is the contemplation that results from engaging with an object or event of beauty (Santayana, 1896/1955; Bundgaard, 2015). However, aesthetic experience can be defined more generally as one that includes a significant positive affect (such as feeling awe or being moved) as a result of contemplation of or engagement with an object or event (Schubert et al., 2016). The present discussion is limited to the perception of art works and excludes aesthetic experiences that occur in response to objects/events that serve a purely practical function and those found in nature. Because the focus of the current investigation is on creativity, we will focus on the special case of the artistic output: when a new work is experienced for the first time. After all, this is when an individual is likely to be struck by the creativity of the new work.

AESTHETIC EXPERIENCE AS TRANSCOMBINATION AND MIRRORING

As discussed in the introduction, veridical chaining is compatible with the spreading activation model. As a fragment of music is heard, a mental representation (node) that matches the unfolding music is activated, and this activated node primes the representation of the next part of the music that has been encoded earlier (**Figure 1**). Hence, familiar music will activate a temporally measured cascade of mental representations, with each mental representation being primed and then activated in succession, synchronized with the unfolding music. With each listening of the familiar pieces, the link strength between those nodes increases. This corresponds to the experience of increasing familiarity. The increasing link strength continues with additional exposure, unless the exposure is high in frequency and massed in which case habituation will occur (discussed below).

However, if a new piece is heard, there may not be as many nodes to activate, or different nodes to the ones that are primed are activated (referred to as disruption of expectation in the influential work of Meyer, 1956). In this case, we may be experiencing something new or novel. This is illustrated in **Figures 2i,iii**, noting the flexibility of the network representation—in the earlier example, the same illustration was used to represent concepts of physical objects (birds and cars), and here it represents music. Upon listening to a new creative work, created by the individual represented in **Figure 2iA**, if the person indicated in **Figure 2iii** initially (that is, at time point A) had the nodes representing the components of music which the person represented by **Figure 2iii** has transcombined, then repeated listenings by the person of **Figure 2iii** will strengthen the links between those through temporal contiguity (**Figure 2iiiB**). Thus in the example, two weakly linked node clusters are activated by the new piece of music, and the initially weak link strength between them is altered, with links strengthening (in the Figure, the dotted line between the two nodes indicates the new formation of a link, which by time point B of **Figure 2iB** has become an established link). The network of person iii, through the perception of person i's created work, comes to mirror the network of person i.

However, for the network of the person represented in **Figure 2ii**, a part of the music is not represented at all (the dark green node cluster is missing because it has never been formed), and so no new activation can take place. The new piece may be assessed as incomprehensible to that person. Similarly, if the two nodes representing the new idea do exist, but are too weakly connected, activation induced by the new music may simply not be sufficient to create or strengthen a link through the intermediating nodes of the network. That is, the stronger the links between node clusters, whether through an alternate pathway via other nodes, or directly between the two, the easier it will be to transcombine them. However, if the two clusters are very strongly linked then the link between the concepts is already represented (familiar), and while potentially generating activation, they do not satisfy the condition of being sufficiently novel to be judged creative. We must therefore now take a closer look at how novelty and usefulness are modeled by SAMOC.

THE DILEMMA OF NOVELTY IN CREATIVITY

Novelty is one of the two common criteria listed when defining creativity (Runco and Jaeger, 2012). An inherent problem is what level of novelty is necessary to constitute an assessment of creativity. Must a particular level of novelty be surpassed (meaning that novelty is categorical), or is there a monotonically positive relationship, where provided other criteria of creativity are met, increases in novelty translate to increases in creativity? Styhre (2006, fn. 1, p. 148) went as far as to suggest that novelty is not central to creativity but rather "connectivity, associations, assemblages and multiplicities point at the combinatory nature of creativity," which is highly compatible with the spreading activation model. Diedrich et al. (2015), on the other hand, evidence the key role novelty plays in creativity.

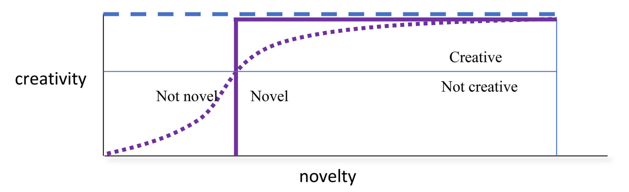

FIGURE 3 | Hypothetical creativity assessment as a function of novelty. Thick solid purple line indicates simple threshold approach to assessing creativity. If novelty exceeds the threshold, the novelty criterion is satisfied. The monotonic increasing function is illustrated by the dotted curve. The functions are adjusted in this illustration such that they produce an assessment of "creative" (i.e., above the thin blue horizontal line) at the same threshold level of novelty. The dashed line is a reminder that the "usefulness" criterion has been met for all levels of novelty shown.

In his discussion of the matter, Kaufmann (2003) reported diverse views in the literature ranging from those who define just "different" as sufficiently meeting the novelty criterion, through to those who apply complicated, crude, or non-distinguishing conceptions of novelty. Treating novelty as an above-threshold category (an object/event is novel or it is not) fails to recognize the existence of degrees of novelty. One solution is to consider the category as a simplification of something that actually varies in concert with creativity itself—more novel is more creative. **Figure 3** illustrates the way that the novelty criterion is interpreted according to the threshold (filled line plot) and monotonic increasing (dotted curve) methods, these being the easiest to pin down to a simple conceptualisation of novelty. As we shall see next, this pattern is in conflict with (or opposes) another criterion of creativity.

THE DILEMMA OF USEFULNESS IN CREATIVITY

Usefulness is the other one of the two basic, and most frequently reported, criteria of creativity (Runco and Jaeger, 2012). The process of creatively solving well-defined problems is highly amendable to assessment in terms of usefulness. If the problem is legitimately solved, the solution is useful. However, more disputed is whether usefulness is a concept that can be aptly applied to creativity in artistic endeavors, where problems are generally ill-defined. Answering the question "how is a song or a symphony useful" could raise a wide range of rather subjective responses, making empirical investigation problematic, and suggests that such a criterion misses the point. Some prefer to apply, instead, the criterion of "value," because it better reflects the personal nature of aesthetic experience of art as judged by the perceiver. Valuing a work of art is a more plausible way of referring to the concept that one is trying to capture when assessing the "usefulness" of a work of art. However, even this term is problematic because value is also to some extent subjective (Weisberg, 2015).

In a critique of creativity definitions, Harrington (2018) suggested reconsideration of an older term, still in use today, of "satisfaction" (Stein, 1953), rather than usefulness or value.

Satisfaction is a term that appears to capture aspects of usefulness and value as applied to the arts and so lends itself to the definition of creativity. Satisfaction also has the advantage of providing a tangible, potentially reliable understanding of the aspect of usefulness relevant to assessing creativity, but it does not capture the richness of the creative and aesthetic artistic experience.

Given the problematic nature of the usefulness criterion, it is worth considering an alternative aspect of creativity that until recently has received less attention but broadens out the limited satisfaction option: the affective component of creativity. There is a growing body of evidence that the mental processing and outcomes of creativity generate positive affect (Russ, 1999; Henderson, 2004; Amabile et al., 2005; Bledow et al., 2013; Tavares, 2016; Gu et al., 2018). Positive affect is a broader concept than satisfaction, incorporating experiences reported as a result of the creative process (such as "aha," "wow," surprise, . . .) (Wiggins, 2006; Macedo et al., 2009; Thagard and Stewart, 2011; Becattini et al., 2017) as well as the reception of the artistic output (e.g., awe, being moved, thrills) (Konečni, 2005; Schubert, 2009-2010; Schubert et al., 2016). Fortunately, there is a straightforward theory about the underlying mental mechanism of positive affect that has been applied to the spreading activation model.

POSITIVE AFFECT AS SPREADING ACTIVATION

Martindale proposed a simple relationship between the net amount of spreading activation and the amount of pleasure experienced—suggesting that they have a monotonic increasing relationship. More activation is experienced as greater pleasure—the "pleasure of thought" principle (Martindale, 1984, for a similar, more recent perspective, see Hofmann and Jacobs, 2014). Despite building this finding around a considerable battery of evidence (for a summary, see Martindale and Moore, 1988), Martindale's ideas have been criticized, above all for the simplistic characterization of aesthetic experiences of beauty, which he was accused of reducing to mere preference (Croft, 2011), a criticism that has its parallel in the criterion of satisfaction applied to creativity, discussed above.

However, this concern has been reconciled in recent years with the idea that preference falls under a broader category of experience labeled "positive affect valence" (or, in the present discussion, "positive affect") (Colombetti, 2005; Schubert, 2013). Schubert et al. (2016) proposed that affect valence could be divided along a number of dimensions—most pertinently here as valence (positive or negative) and hedonic (shallow and deep) tone. Positive affect is a feeling that is contemplative but also drives an individual to repeat, continue, or seek out the future activity that leads to that feeling. It can be thought of as attraction in the broadest sense. Negative affect is a feeling related broadly to aversion, repulsion, aggression, or boredom that usually drives the individual away from the activity that leads to that feeling. Positive affect defines aesthetic experience according to some researchers (see Schubert et al., 2016).

Within positive affect, there are different levels of depth of experience. Empirical aesthetics researchers frequently measure shallow hedonic tone (such as preference, enjoyment, liking) because these are easy to collect and quantify via self-report, and reasonably reliable (e.g., Hardiman and Zernich, 1975). Deep hedonic tone, on the other hand (for example, feelings of awe, being moved, etc.), is considered more reflective of fully fledged aesthetic experience but occurs less frequently (Konečni, 2005). Shallow hedonic tone, when positive (e.g., liking), can therefore be taken to be an index of the broader, richer concept of positive affect, and aesthetic experiences in general, even if it may miss the essence of many aesthetic experiences.

An alternative reason for attraction to art is that engaging with art triggers neuroanatomically localized pleasure centers. The pleasure of thought principle, however, is not dependent on anatomical centers, because pleasure, and positive affect in general, is generated by the process of distributed activation, not the stimulation of a particular, specialized center. While the proposed model does not rely on neuroanatomical evidence (it is a cognitive, conceptual model), it is interesting to note the growing number of studies that refer to networks, circuits, and distributed anatomical structures that are active during periods of pleasure, moving away from specialized center-based locations. For example, Berridge and Kringelbach explain, "wanting for rewards is generated by a large and distributed brain system. Liking, or pleasure itself, is generated by a smaller set of hedonic hotspots within limbic circuitry." (Berridge and Kringelbach, 2015, p. 646; see also Knapp and Kornetsky, 2009; Schubert, 2012; Lesage and Stein, 2016).

POSITIVE AFFECT FROM THE PERCEPTION OF FAMILIAR ART

For the spreading activation model, if activation leads to positive affect (not just preference), perceiving the familiar should produce strong positive response. Activation of a node representing a portion of music that is familiar means that the next, incoming portion of music will activate the node that was already primed, leading to an increase in net activation (**Figure 1**). Evidence supporting this claim is abundant—people like stimuli, and works of art in particular to which they have been previously exposed (Zajonc, 1968, 2001; Finnäs, 1989; Cutting, 2006; Schubert et al., 2014; Chmiel and Schubert, 2017).

However, this leaves us with a puzzle: people should gravitate toward experiencing familiar works of art and never to any new works. New combinations of music representing nodes would not generate as much activation as familiar combinations. Why would anyone want to experience something new and creative according to the SAMOC spreading activation account? There are several reasons, but we shall focus on one for now: that by experiencing only the familiar, habituation will take place. The discussion of habituation that follows turns attention back to creative production, rather than perception (of creative works). However, the principles of pleasure (positive affect) induction from perception described above remain the same as for creative production, because the mental processing takes place in the same network architecture and principles (hence they are mirrored). The shared framework is based Martindale's connectionist approach in which he recognized that "[t]he act of creation, a case of extremely successful cognition, is [. . .] isomorphic with the perception of something of great beauty" and that "the act of creation and the perception of beauty are essentially identical" (Martindale, 2001, p. 25 and p. 33).

HABITUATION

When a node is activated frequently (through massed repetition), the node fatigues and its capacity to transmit to other nodes decline (e.g., due to a decline in its firing rate), ceasing to propagate activation, and itself failing to contribute to the activation. As a result, the individual will stop showing interest in the overexposed stimulus, possibly experiencing negative affect such as boredom (Schubert et al., 2016). The individual can seek other ways of increasing activation. One way to do this is to engage with stimuli that have existing mental representations but have not recently been activated. This gives rise to the finding that artistic stimuli remain much loved over a long period of time (Martindale et al., 1990). However, the revisiting of stimuli after a long absence would not in any obvious way produce a sense that the work was creative, even though its re-perception may well generate considerable pleasure.

Another strategy, of interest here, is to combine existing mental representations in new ways. By forming new combinations between weakly linked nodes, net activation in the network can under some circumstances once again be increased. If one has habituated to a stimulus, then finding another stimulus that provides more activation should not be difficult. The question then becomes, what combination of mental representations would optimize this activation? And pertinent to the current discussion—which combination would also be considered creative? **Figure 2** helps to answer this question. Let us suppose that two adjacent clusters of nodes (consider two node clusters represented as two different colors in the Figure) that are closest to one another are no longer activating due to fatigue. More activation can be generated by turning attention to the links that are weaker, but not fatigued, with a displaced (rather than adjacent) cluster. In the case of the creative endeavor, the creator seeks out the pairs of node clusters that are as far apart as possible, while still containing some (albeit weak) links. Combining these is satisfying (positive affect) because activation is recovered, and also the link strength is increasing between these, until now weakly combined nodes, through the formation of a new, but more direct link (see the dotted line in **Figures 2iA,iiiB**). That is, link strength increases if the transcombination is repeated, or if the two ideas are already sufficiently linked.

In the case of music, this cognitive explanation can be used to model any of the forms of musical delivery discussed above—composition, improvisation, performance, and imagination. Examples of compositional creativity were discussed above. In the case of improvisation, it might be the surprising combination of different ideas (see also Spence, 2021). In classical performance, it might be the satisfying outcome of applying a historically informed interpretation to a piece of music that had not had such treatment. Each of these examples can be explained in terms of transcombination of nodes, and each will be satisfying (i.e., produce positive affect) because existing mental representations have been activated where one or more of the mental representations have not been fatigued, meaning that greater activation is possible than before the creative thought came to mind.

The assumption of this kind of creativity is that mental representations of (in this case) music exist and should not have been previously combined, and that at least one of the nodes being stimulated are not fatigued. The existence of mental representations sets a boundary in terms of what can be considered creative. Novelty alone cannot explain this criterion because novelty alone could mean absence of mental representation, or mental representations that are completely unlinkable to one another. The current model would not produce increasing activation if a link was being made between an existing node and one that does not as yet exist. This is simply not possible. The individual could not process the new object/event without additional experience. The perception of such a combination would be incomprehensible.

OPTIMAL NOVELTY HYPOTHESIS

To optimize activation using novel combinations (as distinct from those that are already well linked), one does *not* select only frequently combined mental representations. Those representations must be inhibited during creative processing to avoid reproduction/replication—by definition not creative, as discussed in Section "Spreading activation model." However, similarly, highly unrelated representations should not be combined because they do not have sufficient, existing link strength, which translates phenomenologically to being too incongruous (too translational, if you like). The rationale for this assertion requires some explanation. Imagine, for example, a highly creative individual, who also has a wide range of experiences (**Figure 2i**). This individual has a large number of mental representations, and the individual has the capacity to combine quite diverse nodes together. Transcombining nodes that are quite conceptually remote will not be as difficult for that person as it would be for someone with less aptitude for creativity and fewer experiences (**Figure 2ii**). Like the regression to the mean problem (Bland and Altman, 1994), the creative individual seeking to appeal to a wide audience rapidly (if that is what she/he is aiming to do)—such as at a premier public presentation (performance, exhibition etc.)—will be better off not selecting the most diverse mental combinations that satisfies perhaps only their own mental network (and hence their own creative goals). Some calibration in the level of novelty of the combination is required to increase the appeal of the creation to a wider cohort. Whether considered too outlandish for the creator, or thought to be too difficult for the target population to process, such unusual combinations, too, will be inhibited. In this case, the creator would not wish to produce something that is new and thrilling (high positive affect) to them because it will miss the mark for the more typical audience. The aim of the creator will be to reach the limits of combinations that the most typical recipient is likely to experience.

An inverted-U of positive affect as a function of novelty is therefore the way to think of producing a creative work. The (possibly unconscious) aim of the creator, in this situation, is to produce node combinations that will maximize the activation of the perceiver. If the creator has no systematic way to directly access this information they would need to do it through intuition, and this may also involve researching their prospective audience. This optimization of the two systems—novelty and positive affect—is illustrated in terms of SAMOC in **Figure 4** and constitutes the optimal novelty hypothesis.

The reasoning for the creator taking control of what nodes to make available for recombination is similar to that used by Martindale, after Eysenck, which hints at the idea of an optimal amount of novelty:

> *if we let nodes come on and off totally at random, the "search space" for problem solving of other than a trivial nature is so large that a solution could never be found. We must cut down what he [Eysenck] calls the "associative horizon" to a reasonable level. If we trim it too far, though, only "relevant" nodes will be activated, and they do not contain the crucial hint. We want a network that will at least periodically go to a low-arousal state in order to "search" for a solution and return to a higher arousal state [activation] to see if the solution is a good one (Martindale, 1995, p. 261).*

EVIDENCE OF NON-EXTREME NOVELTY FROM HISTORICAL RECEPTION OF COMPOSITIONS

Evidence for optimal rather than extreme novelty can be found in the catalog of critically derided first performances of pieces of music that would later become important works of art (Slonimsky, 2000). A striking example is the reception of Beethoven's Ninth Symphony, now treasured as an iconic work in the music repertoire. Early performances were greeted with at times considerable taunts, including outright rejection of some of the symphony's most innovative features—the size of the orchestra, and the final, choral movement, which attracted commentary from William Ayrton about the "acoustic missile" of instruments that

> *. . . made even the ground shake under us, and would, with their fearful uproar, have been sufficiently penetrating to call up from their peaceful graves . . . the revered shades of Tallis, Pursell, and Gibbons, and even of Handel and Mozart, to witness and deplore the obstreperous roarings of the modern frenzy in their art. (cited by Cook, 1993, p. 42).*

and, regarding the innovation of a choral movement, Ayrton remarked

> *[w]hat relation it bears to the symphony we could not make out; and here, as well as in other parts, the want of intelligible design is too apparent. In quitting the present subject, we must express our hope that this new work of the great Beethoven may be put into a produceable form; that the repetitions may be omitted, and* ***the chorus removed altogether****; the symphony will then be heard with unmixed pleasure, and the reputation of its author will, if possible, be further augmented. (cited by Cook, 1993, p. 43) [emphasis added].*

Beethoven's transcombination of choral music and symphony was not mirrored by this critic.

There are documented cases when Beethoven deliberately chose weakly linked nodes to transcombine, reflected in his disdain for audiences who found his music incomprehensible. Novelist and critic Ludwig Rellstab was one of those who was perplexed by Beethoven's later works, but when speaking with Beethoven recounted to the composer a performance of the Op. 127 quartet, stating: "'It had been carefully practiced and was played twice in immediate succession'. Beethoven's reply was: 'That is well. It must be heard several times'" (Adelson, 1998, p. 236). Beethoven's presumed reply is realized in the spreading activation model as different musical material being too unrelated for some audience members, and so needing further exposure to increase the link strength between the new musical ideas, or, if necessary, to form the musical ideas that are not yet represented.

For highly creative, highly experienced individuals, their positive affect function of novelty (**Figure 4**) will be broader than that of the typical person, and unless they are willing to wait for future acceptance or even recognition of their creativity (Beethoven, Wagner, and Schoenberg had each indicated that they were writing music for the future—see, e.g., Hueffer, 1874), they would need to produce works that made less novel combinations for them than they may typically do. Beethoven did with his "Battle Symphony," Wellington's Victory, which quoted familiar patriotic tunes and applied real-life military sound effects—all familiar to the large audiences that adored the work, but the piece would come, in time, to be considered an embarrassment by later connoisseurs of Beethoven's music (Cook, 2003). Furthermore, composers also made changes to their compositions if the pieces were received poorly (Anderson, 2017). Each of these cases points to a calibration that composers may or may not make to their new compositions for audience accessibility, while remaining creative, or that some form of repetition is needed so that the audience can process the newly connected ideas, and, from the SAMOC perspective, increase the link strength between them, hence increasing positive affect.

EVIDENCE OF TRANSCOMBINATION FROM A MUSIC ANALYSIS PERSPECTIVE

There is abundant evidence of the creative process in music composition consisting of modifications or adaptations of preexisting musical fragments and, unless explicitly quoted, appearing in the new composition as a result of unconscious processing. The creator need not have conscious awareness of the transcombination of existing musical ideas, such as musical fragments (**Figure 1**) and templates (formal structure, beat pattern, harmonic progression, etc.). Cope refers to these as musical allusions, and Jan, building on Cope's groundwork, as

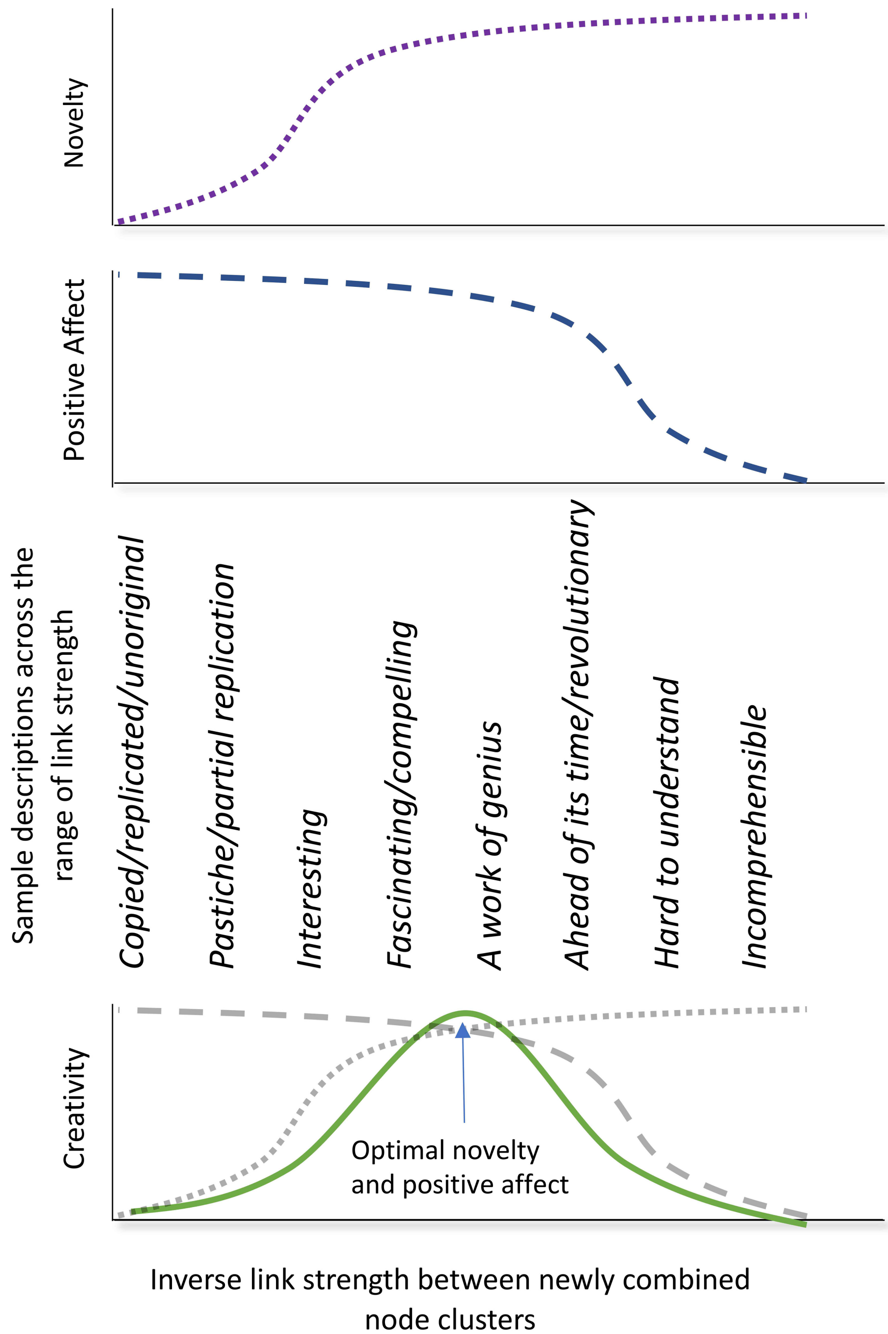

FIGURE 4 | Demonstration of the optimal novelty hypothesis—why novelty must be at an intermediate level rather than monotonic increasing to maximise creativity. The top curve indicates the implicit alternative (conventional) view that novelty increases monotonically as a function of decreasing link strength between transcombined node clusters. That is, more conceptually distant node clusters have a weaker link strength than node clusters that are conceptually more related. Below this is a plot of the activation strength decreasing as link strength decreases. Here activation is related to positive affect, and so we see less positive affect as more novelty is experienced. The bottom, green curve shows the schematic superposition of these two curves, which gives rise to a maximal level of creativity, where creativity is defined in terms of optimal novelty and positive affect. Note that positive affect is proposed as a better indicator than "usefulness" when assessing creative works, as explained in the body text.

memes. For Jan "any discrete musical segment which a composer assimilates from his or her cultural environment may be regarded as memetic" (Jan, 2007, p. 60). The important point here is that the allusions or memes are generally fragmentary and that a single meme cannot on its own constitute a new work, unless the new work is intentionally presented as a tribute or quotation (or more euphemistically, "borrowing." see also Burkholder, 1994). That is, if a meme is too long (temporally, or structurally), or the similarity to its source is too salient, the assessment of the work as a new creation is inhibited.

Furthermore, transcombination and exploratory (as distinct from transformational) forms of creativity suggest that new composition will consist of stitching together of different memes. Jan (2015) presents sophisticated accounts of how this works based on his bio-evolutionarily inspired analytic technique. In one analysis, he presented a score of a phrase from Beethoven's Piano Sonata op. 110, Movement I, and mapped out the sources of the identifiable memes. Within the space of a few bars, links were made to works by Haydn, Mozart, J. S. Bach, and Beethoven's own earlier outputs. Jan was cautious to point out the complexity of performing such an analysis, with two critical issues worth mentioning here. First, a musical meme transmits through several pieces of music, from person to person, and generation to generation. To select a single source of the meme simply indicates that it has been in existence, rather than meaning that the principle, single source of origin has been located. Second, performing such an analysis is extremely difficult without extensive knowledge of music. Jan (2004) points out that the vast amounts of information that needs to be parsed by the researcher requires computation tools, which are far from fully developed. That is to say, if one fails to parse a piece of music into its component memes, it could mean that the transcombination explanation is unsupported, but it could also mean that the memes have yet to be located. The present paper hinges on the latter case prevailing.

CONCLUSION

This paper proposed a spreading activation model to generate theory about creativity—SAMOC. As a result, the conventional definition of creativity—that it is the process leading to useful and novel outcomes—came into question. By viewing ideas as nodes that are part of a massively interconnected network operating under reasonably simple principles, a proposal for an alternate definition of creativity presented.

In everyday language, creativity is the process that leads to an outcome that generates positive affect (e.g., pleasure) and is optimally (not extremely) novel. In terms of the spreading activation model from which these conclusions were drawn, and in more rigorous language, creativity is the process of transcombining (forming new combinations of existing) nodes such that they produce a large amount of net activation, even though they will have progressively weaker links between one or more pairs of the nodes in question as novelty increases. In brief, the creative work can be defined as a work which is sufficiently novel to produce positive affect. This is in contrast to conventional definitions that focus on usefulness and novelty. Usefulness cannot be a criterion of a work of art unless the usefulness is mediated by some other criterion. That criterion is the aesthetic experience, which is the positive affect that occurs due to the contemplation of or engagement with (usually) a work of art.

Creativity by one person and the perception of creativity by another person are intricately related through cognitive organization. Based on the above argument, the relationship can be thought of as the successful mirroring of the transcombinations of existing nodes by the perceiver of the creation. The creator and perceiver must each share node representations, and the nodes which have been newly combined by the creator must also be newly combined by the perceiver. The creator chose that combination of nodes because it produced a significant amount of spreading activation, and therefore positive affect. The perceiver, in the process of transcombining the corresponding nodes, also experiences positive affect, and this is caused, according to the present account, by the additional spread of activation that the newly formed connection generates.

While the focus of the present investigation was on ill-defined problems—namely, the creation of artistic works—the newly proposed criteria for creativity may apply to creative solutions to well-defined problems. It seems likely that usefulness will correlate highly with positive affect. Evidence is emerging of the positive affect that is associated with the creativity of new outputs and the reception of those outputs (Russ, 1999; Henderson, 2004; Amabile et al., 2005; Wiggins, 2006; Macedo et al., 2009; Thagard and Stewart, 2011; Bledow et al., 2013; Tavares, 2016; Becattini et al., 2017; Gu et al., 2018). The question for future research is whether this positive affect is a substitute for usefulness, an enhancement of usefulness, a completely separate criterion, or simply a by-product of creativity. The optimal novelty hypothesis, too, may apply to creative solutions for well-defined problems. Although novelty is not such an important criterion for well-defined problems, according to the optimal novelty hypothesis, if a well-defined problem has several solutions, the most creative solution will be the one with an intermediate, rather than a very high amount of novelty.

The proposed model and the predictions it makes are testable. The evidence reported in this paper focused on historical documents about Western music composers, and examination of an innovative meme identification analytic technique of the musical record. However, the theory also makes empirically testable predictions, particularly with regard to degree of novelty that is required to procure a judgment of creativity. For example, a carefully designed study could investigate creativity ratings of three artistic outputs that exhibit different levels of novelty. The optimal novelty hypothesis states that the most creative output will be the one that is slightly less novel than the most extremely novel output, but more novel than the least novel output, when all other factors are held constant. That is, the optimal novelty hypothesis is falsifiable, and the historical evidence reported lends support, but more controlled testing is needed.

The model is also compatible with the data presented by Diedrich et al. (2015) that argues for the primacy of novelty in determining creativity, even for products initiated through ill-defined (artistic) criteria. The primacy argument holds that if and only if the product is novel might it be considered creative. That is, by arguing that an intermediate amount of novelty optimizes creativity, the critical role of novelty in creativity is not at all diminished. Furthermore, the model can be applied to different categories of emotion. Even though the evidence presented in this paper is based on the "Big-C" creativity because it drew data from culturally eminent musicians, the network architecture employed still operates on the same principles for non-eminent categories of creativity that are concerned with everyday and developmental aspects of creativity (Beghetto and Kaufman, 2007; Schubert, 2012).

The SAMOC spreading activation model provides a framework for understanding creativity and has helped to interpret findings from a theoretical perspective. Having the theoretical framework that builds on past conceptualizations of mental processing, memory, and creativity will help to provide structure and direction for future research programs in creativity as well as other human behavioral pursuits.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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REFERENCES

Adelson, R. (1998). Beethoven's string quartet in E flat op. 127: a study of the first performances. *Music and Letters* 79, 219–243. doi: 10.1093/ml/79.2.219

Aldwell, E. (1989). *Harmony and voice leading*, 2nd Edn. Fort Worth, TX: Harcourt Brace Jovanovich.

Amabile, T. M., Barsade, S. G., Mueller, J. S., and Staw, B. M. (2005). Affect and creativity at work. *Administrative Science Quarterly* 50, 367–403. doi: 10.2189/asqu.2005.50.3.367

Amabile, T. M., and Pratt, M. G. (2016). The dynamic componential model of creativity and innovation in organizations: Making progress, making meaning. *Research in organizational behavior* 36, 157–183. doi: 10.1016/j.riob.2016.10.001

Anderson, J. (2017). On the practice of repeating concert items in concerts of modern or contemporary music: Historical precedents and recent contexts. *Participations: International Journal of Audience Research* 14, 116–134.

Baer, J. (2016). "Creativity Doesn't Develop in a Vacuum," in *New Directions for Child and Adolescent Development*, Vol. 151, ed. B. Barbot (San Francisco, CA: John Wiley & Sons, Ltd), 9–20. doi: 10.1002/cad.20151

Beaty, R. E., and Silvia, P. J. (2012). Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. *Psychology of aesthetics, creativity, and the arts.* 6, 309–319. doi: 10.1037/a0029171

Becattini, N., Borgianni, Y., Cascini, G., and Rotini, F. (2017). Surprise and design creativity: investigating the drivers of unexpectedness. *International journal of design creativity and innovation.* 5, 29–47. doi: 10.1080/21650349.2015.1090913

Beghetto, R. A., and Kaufman, J. C. (2007). Toward a broader conception of creativity: A case for "mini-c" creativity. *Psychology of Aesthetics, Creativity, and the Arts* 1, 73–79. doi: 10.1037/1931-3896.1.2.73

Berridge, K. C., and Kringelbach, M. L. (2015). Pleasure systems in the brain. *Neuron* 86, 646–664. doi: 10.1016/j.neuron.2015.02.018

Bland, J. M., and Altman, D. G. (1994). Regression towards the mean. *BMJ : British medical journal /* 308, 1499. doi: 10.1136/bmj.308.6942.1499

Bledow, R., Rosing, K., and Frese, M. (2013). A Dynamic Perspective on Affect and Creativity. *The Academy of Management journal.* 56, 432–450. doi: 10.5465/amj.2010.0894

Boden, M. A. (1994). Precis of The creative mind: Myths and mechanisms–Comment/reply. *Behavioral and brain sciences* 17, 519–531. doi: 10.1017/S0140525X0003569X

Boden, M. A. (2004). *The creative mind: Myths and mechanisms*, 2nd Edn. London: Routledge.

Bundgaard, P. F. (2015). Feeling, meaning, and intentionality—a critique of the neuroaesthetics of beauty. *Phenomenology and the cognitive sciences.* 14, 781–801. doi: 10.1007/s11097-014-9351-5

Burkholder, J. P. (1994). The uses of existing music: Musical borrowing as a field. *Notes* 50, 851–870. doi: 10.2307/898531

Cage, J. (1961/2011). *Silence: Lectures and Writings*. Connecticut: Wesleyan University Press.

Cai, D. J., Mednick, S. A., Harrison, E. M., Kanady, J. C., and Mednick, S. C. (2009). REM, not incubation, improves creativity by priming associative networks. *Proceedings of the National Academy of Sciences of the United States of America.* 106, 10130–10134. doi: 10.1073/pnas.0900271106

Chmiel, A., and Schubert, E. (2017). Back to the inverted-U for music preference: A review of the literature. *Psychology of Music* 45, 886–909. doi: 10.1177/0305735617697507

Churchland, P. S. (1992). *The computational brain*. Cambridge, MA: MIT Press.

Colombetti, G. (2005). Appraising valence. *Journal of Consciousness Studies* 12, 103–126.

Cook, N. (1993). *Beethoven, Symphony no. 9*. New York, NY: Cambridge University Press.

Cook, N. (2003). The Other Beethoven: Heroism, the Canon, and the Works of 1813—14. *19th-century music* 27, 3–24. doi: 10.1525/ncm.2003.27.1.3

Cope, D. (2006). *Computer Models of Musical Creativity*. Cambridge, MA: The MIT Press.

Cope, D. (ed.) (2001). *Virtual Music: Computer Synthesis of Musical Style*. Cambridge, MA: MIT Press.

Croft, J. (2011). The Challenges of Interdisciplinary Epistemology in Neuroaesthetics. *Mind, brain and education* 5, 5–11. doi: 10.1111/j.1751-228X.2011.01103.x

Cutting, J. E. (2006). "The mere exposure effect and aesthetic preference," in *New directions in aesthetics, creativity and the arts*, eds P. Locher, C. Martindale, and L. Dorfman (Amityville, NY: Baywood Publ), 33–46. doi: 10.4324/9781315224084-4

Dennett, D. (2001). "Collision, Detection, Muselot, and Scribble: Some Reflections on Creativity," in *Virtual Music, Computer Synthesis of Musical Style*, ed. D. Cope (Cambridge, MA: MIT Press), 283–291.

Diedrich, J., Benedek, M., Jauk, E., and Neubauer, A. C. (2015). Are creative ideas novel and useful? *Psychology of aesthetics, creativity, and the arts.* 9, 35–40. doi: 10.1037/a0038688

DiPaola, S., and Gabora, L. (2009). Incorporating characteristics of human creativity into an evolutionary art algorithm. *Genetic Programming and Evolvable Machines* 10, 97–110. doi: 10.1007/s10710-008-9074-x

Finnäs, L. (1989). How Can Musical Preferences Be Modified - A Research Review. *Bulletin of the Council for Research in Music Education* 102, 1–58.

Friedman, R. S., Fishbach, A., Förster, J., and Werth, L. (2003). Attentional Priming Effects on Creativity. *Creativity research journal.* 15, 277–286. doi: 10.1080/10400419.2003.9651420

Gabora, L. (2000). "Toward a theory of creative inklings," in *Art, Technology, and Consciousness*, ed. R. Ascott (Bristol: Intellect Press), 159–164.

Gabora, L. (2002). "*Cognitive mechanisms underlying the creative process.* Paper presented at the C&C '02," in *Proceedings of the 4th conference on Creativity & cognition, Loughborough, UK* (Loughborough).

Gabora, L. (2007). The artful mind: Cognitive science and the riddle of human creativity. *Philosophical Psychology* 20, 669–674.

Gabora, L. (2010). Revenge of the "Neurds": Characterizing Creative Thought in Terms of the Structure and Dynamics of Memory. *Creativity Research Journal* 22, 1–13. doi: 10.1080/10400410903579494

Gabora, L. (2016). Honing Theory: A Complex Systems Framework for Creativity. *Nonlinear Dynamics, Psychology, and Life Sciences* 21, 35–88.

Gatherer, D. (1997). The evolution of music—A comparison of Darwinian and dialectical methods. *Journal of social and evolutionary systems.* 20, 75–92. doi: 10.1016/S1061-7361(97)90030-8

Gilhooly, K. J. (2016). Incubation and Intuition in Creative Problem Solving. *Frontiers in Psychology* 7:1076. doi: 10.3389/fpsyg.2016.01076

Gilhooly, K. J., Ball, L. J., and Macchi, L. (2015). Insight and creative thinking processes: Routine and special. *Thinking & reasoning.* 21, 1–4. doi: 10.1080/13546783.2014.966758

Glaveanu, V. P., Hanchett Hanson, M., Baer, J., Barbot, B., Clapp, E. P., Corazza, G. E., et al. (2020). Advancing Creativity Theory and Research: A Socio-cultural Manifesto. *The Journal of Creative Behavior* 54, 741–745. doi: 10.1002/jocb.395

Gros, C. (2015). *Complex and Adaptive Dynamical Systems: A Primer*. Cham: Springer International Publishing AG.

Gu, S., Gao, M., Yan, Y., Wang, F., Tang, Y.-Y., and Huang, J. H. (2018). The Neural Mechanism Underlying Cognitive and Emotional Processes in Creativity. *Frontiers in Psychology* 9:1924. doi: 10.3389/fpsyg.2018.01924

Hardiman, G. W., and Zernich, T. (1975). Integrative review: Some considerations for the measurement of preference in the visual arts. *Review of Research in Visual Arts Education* 2, 1–14.

Harrington, D. M. (2018). On the Usefulness of "Value" in the Definition of Creativity: A Commentary. *Creativity research journal.* 30, 118–121. doi: 10.1080/10400419.2018.1411432

Hebb, D. O. (1949). *The organisation of behavior*. London: Chapman and Hall.

Henderson, S. J. (2004). Product Inventors and Creativity: The Finer Dimensions of Enjoyment. *Creativity research journal.* 16, 293–312. doi: 10.1080/10400419.2004.9651460

Hofmann, M. J., and Jacobs, A. M. (2014). Interactive activation and competition models and semantic context: From behavioral to brain data. *Neuroscience & Biobehavioral Reviews* 46, 85–104. doi: 10.1016/j.neubiorev.2014.06.011

Howes, M., and O'Shea, G. (2014). *Human Memory: A Constructivist View*. San Diego, CA: Academic Press.

Hueffer, F. (1874). *Richard Wagner and the Music of the Future*. London: Chapman and Hall.

Jacoby, L. L., and Witherspoon, D. (1982). Remembering without awareness. *Canadian journal of psychology : Revue canadienne de psychologie.* 36, 300–324. doi: 10.1037/h0080638

Jan, S. B. (2004). Meme Hunting with the Humdrum Toolkit: Principles, Problems, and Prospects. *Computer Music Journal* 28, 68–84. doi: 10.1162/0148926042728403

Jan, S. B. (2007). *The memetics of music: A neo-Darwinian view of musical structure and culture*. Farnham: Ashgate Publishing, Ltd.

Jan, S. B. (2015). A memetic analysis of a phrase by Beethoven: Calvinian perspectives on similarity and lexicon-abstraction. *Psychology of Music* 44, 443–465. doi: 10.1177/0305735615576065

Kahn, D. (1997). John Cage: silence and silencing. *The Musical Quarterly* 81, 556–598. doi: 10.1093/mq/81.4.556

Kaufmann, G. (2003). What to Measure? A new look at the concept of creativity. *Scandinavian journal of educational research.* 47, 235–251. doi: 10.1080/00313830308604

Knapp, C. M., and Kornetsky, C. (2009). "Neural basis of pleasure and reward," in *Handbook of Neuroscience for the Behavioral Sciences*, eds G. G. Berntson and J. T. Cacioppo (Hoboken, NJ: John Wiley & Sons), 781–806.

Konečni, V. J. (2005). The aesthetic trinity: Awe, being moved, thrills. *Bulletin of Psychology and the Arts* 5, 27–44.

Langley, P., and Jones, R. (1988). "A computational model of scientific insight," in *The Nature of Creativity: Contemporary Psychological Perspectives*, ed. R. J. Sternberg (Cambridge: Cambridge University Press), 171–201.

Lavazza, A., and Manzotti, R. (2013). An externalist approach to creativity: discovery versus recombination. *Mind & Society* 12, 61–72. doi: 10.1007/s11299-013-0124-6

Lesage, E., and Stein, E. A. (2016). "Networks Associated with Reward," in *Neuroscience in the 21st Century: From Basic to Clinical*, eds D. W. Pfaff and N. D. Volkow (New York, NY: Springer New York), 1677–1703. doi: 10.1007/978-1-4939-3474-4_134

Macedo, L., Cardoso, A., Reisenzein, R., and Lorini, E. (2009). "Artificial surprise," in *Handbook of research on synthetic emotions and sociable robotics: New applications in affective computing and artificial intelligence*, eds J. Vallverdú and D. Casacuberta (London: Information Science Reference), 267–291. doi: 10.4018/978-1-60566-354-8.ch015

Martindale, C. (1984). The pleasures of thought: A theory of cognitive hedonics. *Journal of Mind & Behavior* 5, 49–80.

Martindale, C. (1995). "Creativity and connectionism," in *The creative cognition approach*, eds S. M. Smith, T. B. Ward, and R. A. Finke (Cambridge, MA: The MIT Press), 249–268.

Martindale, C. (1999). "Biological bases of creativity," in *Handbook of creativity*, ed. R. J. Sternberg (Cambridge: Cambridge University Press), 137–152. doi: 10.1017/cbo9780511807916.009

Martindale, C. (2001). How does the brain compute aesthetic experience. *The General Psychologist* 36, 25–35.

Martindale, C., and Moore, K. (1988). Priming, prototypicality, and preference. *Journal of Experimental Psychology: Human Perception & Performance* 14, 661–670. doi: 10.1037/0096-1523.14.4.661

Martindale, C., Moore, K., and Borkum, J. (1990). Aesthetic preference: Anomalous findings for Berlyne's psychobiological theory. *American Journal of Psychology* 103, 53–80. doi: 10.2307/1423259

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological review* 69, 220–232. doi: 10.1037/h0048850

Meyer, L. B. (1956). *Emotion and meaning in music*. Chicago, IL: University of Chicago Press.

Mills, C., Herrera-Bennett, A., Faber, M., and Christoff, K. (2018). "Why the mind wanders: How spontaneous thought's default variability may support episodic efficiency and semantic optimization," in *The Oxford handbook of spontaneous thought: Mind-wandering, creativity, and dreaming*, eds K. Christoff and K. C. R. Fox (New York, NY: Oxford University Press), 11–22.

Pétervári, J., Osman, M., and Bhattacharya, J. (2016). The Role of Intuition in the Generation and Evaluation Stages of Creativity. *Frontiers in Psychology* 7:1420. doi: 10.3389/fpsyg.2016.01420

Rameau, J.-P. (1722/1971). *Treatise on Harmony*. New York, NY: Dover Publications. Trans. P. Gossett.

Ranjan, A., and Gabora, L. (2013). *How Insight Emerges in a Distributed, Content-Addressable Memory*. Cambridge, MA: The MIT Press.

Reitman, W. R. (1965). *Cognition and thought: an information processing approach*. New York, NY: John Wiley & Sons, Inc.

Runco, M. A., and Jaeger, G. J. (2012). The Standard Definition of Creativity. *Creativity Research Journal* 24, 92–96. doi: 10.1080/10400419.2012.650092

Russ, S. W. (1999). "Play, affect, and creativity: Theory and research," in *Affect, creative experience and psychological adjustment*, ed. S. Russ (Philadelphia, PA: Brunner/Mazel), 57–75.

Santayana, G. (1896/1955). *The sense of beauty*. New York, NY: Dover Publications.

Schoenberg, A. (1950). *Style and Idea*. New York, NY: Philosophical Library.

Schooler, J. W. (1999). Why creativity is not like the proverbial typing monkey. *Psychological inquiry.* 10, 351. doi: 10.1177/1029864909013002051

Schubert, (2009-2010). The fundamental function of music. *Musicae Scientiae* 13, 63–81.

Schubert, E. (2012). "Spreading activation and dissociation: A cognitive mechanism for creative processing in music," in *Musical Imaginations Multidisciplinary perspectives on creativity, performance, and perception*, eds D. J. Hargreaves, D. E. Miell, and R. A. R. MacDonald (Oxford: Oxford University Press), 124–140.

Schubert, E. (2013). Loved music can make a listener feel negative emotions. *Musicae Scientiae* 17, 11–26. doi: 10.1177/1029864912461321

Schubert, E. (2015). "Reconsidering expectancy and implication in music: The Veridical Chaining hypothesis," in *Paper presented at the Ninth Triennial Conference of the European Society for the Cognitive Sciences of Music, RNCM, Manchester, UK* (Manchester).

Schubert, E., Hargreaves, D. J., and North, A. C. (2014). A dynamically minimalist cognitive explanation of musical preference: Is familiarity everything? *Frontiers in Psychology* 5:38. doi: 10.3389/fpsyg.2014.00038

Schubert, E., North, A. C., and Hargreaves, D. J. (2016). Aesthetic Experience explained by the Affect-space framework. *Empirical Musicology Review* 11, 330–345. doi: 10.18061/emr.v11i3-4.5115

Schubert, E., and Pearce, M. (2015). "Veridical Chaining: A case-based memory matching approach to the mental organization of music," in *Paper presented at the 11th International Symposium on Computer Music Multidisciplinary Research (CMMR), Plymouth, UK* (Plymouth).

Simonton, D. K. (2000). Creativity - Cognitive, personal, developmental, and social aspects. *American Psychologist* 55, 151–158. doi: 10.1037/0003-066x.55.1.151

Sio, U. N., and Rudowicz, E. (2007). The Role of an Incubation Period in Creative Problem Solving. *Creativity research journal.* 19, 307–318. doi: 10.1080/10400410701397453

Slonimsky, N. (2000). *Lexicon of musical invective: critical assaults on composers since Beethoven's time*. New York, NY: WW Norton & Company.

Smolensky, P. (1988). On the proper treatment of connectionism. *Behavioral and brain sciences* 11, 1–23. doi: 10.1017/s0140525x00052432

Spence, A. (2021). The experimental composition improvisation continua model: a tool for musical analysis. *Front. Psychol.* 12:611536. doi: 10.3389/fpsyg.2021.611536

Stein, M. I. (1953). Creativity and Culture. *The Journal of psychology.* 36, 311–322. doi: 10.1080/00223980.1953.9712897

Styhre, A. (2006). Organization Creativity and the Empiricist Image of Novelty. *Creativity and innovation management.* 15, 143–149. doi: 10.1111/j.1467-8691.2006.00386.x

Tavares, S. M. (2016). How does creativity at work influence employee's positive affect at work? *European journal of work and organizational psychology.* 25, 525–539. doi: 10.1080/1359432X.2016.1186012

Thagard, P., and Stewart, T. C. (2011). The AHA! Experience: Creativity Through Emergent Binding in Neural Networks. *Cognitive Science* 35, 1–33. doi: 10.1111/j.1551-6709.2010.01142.x

Vartanian, O., Martindale, C., and Kwiatkowski, J. (2003). Creativity and inductive reasoning: The relationship between divergent thinking and performance on Wason's 2-4-6 task. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology* 56, 641–655.

Vartanian, O., Martindale, C., and Kwiatkowski, J. (2007). Creative potential, attention, and speed of information processing. *Personality and Individual Differences* 43, 1470–1480. doi: 10.1016/j.paid.2007.04.027

Wagner, R. (1987). *Selected letters of Richard Wagner*. London: J. M. Dent.

Walia, C. (2019). A Dynamic Definition of Creativity. *Creativity Research Journal* 31, 237–247. doi: 10.1080/10400419.2019.1641787

Weisberg, R. W. (2015). On the Usefulness of "Value" in the Definition of Creativity. *Creativity research journal.* 27, 111–124. doi: 10.1080/10400419.2015.1030320

Welch, L. (1946). Recombination of ideas in creative thinking. *Journal of applied psychology.* 30, 638–643. doi: 10.1037/h0054074

Wiggins, G. A. (2006). A preliminary framework for description, analysis and comparison of creative systems. *Knowledge-Based Systems* 19, 449–458. doi: 10.1016/j.knosys.2006.04.009

Wu, X., Guo, T., Tang, T., Shi, B., and Luo, J. (2017). Role of Creativity in the Effectiveness of Cognitive Reappraisal. *Frontiers in Psychology* 8:1598. doi: 10.3389/fpsyg.2017.01598

Zajonc, R. B. (1968). Attitudinal Effects Of Mere Exposure. *Journal of Personality & Social Psychology* 9, 1–27. doi: 10.1037/h0025848

Zajonc, R. B. (2001). Mere exposure: A gateway to the subliminal. *Current Directions in Psychological Science* 10, 224–228. doi: 10.1111/1467-8721.00154

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Beta and Theta Oscillations Correlate With Subjective Time During Musical Improvisation in Ecological and Controlled Settings: A Single Subject Study

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In this paper, we describe the results of a single subject study attempting at a better understanding of the subjective mental state during musical improvisation. In a first experiment, we setup an ecological paradigm measuring EEG on a musician in free improvised concerts with an audience, followed by retrospective rating of the mental state of the improviser. We introduce Subjective Temporal Resolution (STR), a retrospective rating assessing the instantaneous quantization of subjective timing of the improviser. We identified high and low STR states using Hidden Markov Models in two performances, and were able to decode those states using supervised learning on instantaneous EEG power spectrum, showing increases in theta and alpha power with high STR values. In a second experiment, we found an increase of theta and beta power when experimentally manipulating STR in a musical improvisation imagery experiment. These results are interpreted with respect to previous research on flow state in creativity, as well as with the temporal processing literature. We suggest that a component of the subjective state of musical improvisation may be reflected in an underlying mechanism related to the subjective quantization of time. We also demonstrate the feasibility of single case studies of musical improvisation using brain activity measurements and retrospective reports, by obtaining consistent results across multiple sessions.

Keywords: improvisation (music), EEG, ecological, flow state, machine learning, subjective time

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1. INTRODUCTION

> Improvisation enjoys the curious distinction of being both the most widely practiced of all musical activities, and the least understood and acknowledged. (Bailey, 1982)

Fourty years have passed since Derek Bailey wrote these words (Bailey, 1982), and musical improvisation has now been widely acknowledged as a model to investigate the neuroscience of creativity (Beaty, 2015; Landau and Limb, 2017). A wealth of studies done in the last 15 years have attempted to elucidate the neural correlates of musical improvisation, mostly through hypothesis-driven research, and broadly asking questions of two types: (1) what makes brain activity during improvisation different than other music-related activity, and (2) is there long term plasticity associated with the (expert) practice of improvisation (Beaty, 2015). Much of these hypotheses seem driven by initial accounts proposed by the theoretical framework from Pressing (Pressing, 1988, 1998), which considers improvisation as a complex activity requiring significant domain-specific expertise related to musical training such as sensorimotor synchronization, motor planning, procedural memory for accurate sensorimotor execution, as well as a combination of a range of cognitive functions such as long term memory and generative processes involved in creativity (Pressing, 1988). A wealth of neuroscientific studies have confirmed the role of many brain networks such as the executive control network, notably involved in regulating attention and working memory, as well as the default mode network which mediates mental simulation (e.g., mental time travel) and mind wandering (Beaty, 2015). Studies have shown that while the activity in these two networks were traditionally considered as anti-correlated (Raichle, 2015), they can operate concurrently during musical improvisation (Pinho et al., 2015). More recently, authors have proposed that motor and premotor regions are also involved in musical improvisation, possibly managing temporal aspects of performance (Bashwiner and Bacon, 2019). Taken together, these studies have brought light on brain areas that are important for musical improvisation, either because they are activated during performance, or because of long term plasticity effects associated with expertise.

Most of the aforementionned studies have used functional MRI in order to shed light on the spatial location of brain networks involved in improvisation. Many other studies have used electroencephalography (EEG) and magnetoencephalography, in order to get a finer temporal understanding of neuronal activity during improvisation. Studies have found improvisation related activity in the alpha (8–12 Hz) and beta (13–30 Hz) frequency ranges (Dolan et al., 2013; Boasen et al., 2018; Stevens and Zabelina, 2019) located in prefrontal and medial frontal areas, while other studies have examined brain connectivity (Müller et al., 2013; Wan et al., 2014) or power changes at the sensor level (Dikaya and Skirtach, 2015; Sanyal et al., 2016; Sasaki et al., 2019).

Another perspective developed in the literature consists in considering musical improvisation as a *subjective state* (Beaty, 2015; Lopata et al., 2017; Dolan et al., 2018; Tan and Sin, 2019). Such an angle considers primarily musical improvisation as an instance of flow state. Flow state is defined as "the holistic sensation that people feel when they act with total involvement," Csikszentmihalyi (1975), and has been extensively studied with respect to many domains of subjective experience including creativity and aesthetics, but also in other activities requiring full subject engagement such as sports (Csikszentmihalyi, 1990). Flow state has been studied in the context of the musical improvisation (e.g., see Chirico et al., 2015; Dolan et al., 2018; Luft et al., 2018; Tan and Sin, 2019). These studies have discussed the involvement of brain networks of spontaneous, endogenous activity such as the default mode network (Pinho et al., 2015), and considers the notion of flow state as central in the phenomenology of musical improvisation (Tan and Sin, 2019). Interview and observation studies have noted that the concepts usually discussed relating musical improvisation and flow state are selflessness, dream-like experiences, modulation in the passage of time, various forms of mental imagery, and a sense of disconnection with reality (Tan and Sin, 2019; Barrett et al., 2020). Therefore, previous literature suggest that the subjective experience of musical improvisation is rich and complex, as well as idiosyncratic, which motivates the need for qualitative studies using single cases or structured interviews.

Single case studies are quite common in music studies of improvisation, and have attempted at characterizing the creative process (Wopereis and Derix, 2016; Wopereis and Braam, 2017). Interview studies using small groups of expert musicians were also done to investigate group dynamics in musical improvisation (Wilson and MacDonald, 2016), as well as subjective assessment of musical qualities (Wopereis et al., 2013; Pras et al., 2017). Interestingly, these studies show that musicians do not necessarily agree on what makes a good musical improvisation, which suggest that the study of musical improvisation on single cases might give unique insights on the cognitive and neural basis of creativity. A recent single case study on a internationally acclaimed musical improviser attempted at examining brain activity during improvisation using fMRI using a classical block-design with controlled experimental conditions (Barrett et al., 2020). Results suggested the involvement of large scale brain networks beyond mere auditory and motor activity, such as visual areas, parietal cortices and areas of the default mode network, thus agreeing with previous group results (Pinho et al., 2015).

However, the complexity and idiosyncrasy of musical improvisation might not be ideally captured using controlled experiments that compared improvisation with "non-improvisation" conditions, or mere effects of expertise in improvisation on brain plasticity, paradigms which are used in the vast majority of studies as shown in Beaty (2015). To address this bias, it has been argued that the study of the neuroscience of creativity, and in particular musical improvisation, would be better approached by setting up collaborations between scientists and artists in order to achieve both ecological and scientific validity (McPherson and Limb, 2013). Notably, a recent study performed EEG measurements on performers and audience in a live concert (Dolan et al., 2018). Results demonstrate potential neural correlates of flow state using a measure of signal complexity, and this study more generally shows the feasibility of such ecological designs to better understand musical improvisation in a live context (Dolan et al., 2018).

Building upon these different directions, our goal is to study musical improvisation from the point of view of an improviser, by implicating the musician in the scientific design of the experiment. We propose here to setup a collaborative process with the musician in order to define an appropriate paradigm, and repeated this paradigm in a series of rehearsals and public performances. Our objective is to maximize ecological validity by studying a single subject on many occasions, in an attempt at generalizing findings within this subject. By doing so, we also hope that such an approach can be of interest for the musician itself, by providing some scientific insights toward an introspection of his creative process.

The rest of this paper is organized as follows. In section 2, we describe our general setting, the collaboration with the artist, and the definition of an ecological paradigm to study musical improvisation. We performed EEG measurements on a musician during live concerts, followed by retrospective ratings of the performance. This paradigm has led us to consider a new hypothesis to test with regards to subjective time during musical improvisation. We present in section 3 a controlled paradigm designed to test this hypothesis. Finally, we discuss our results and our approach in section 4.

2. EXPERIMENT 1 : ECOLOGICAL PARADIGM

2.1. Materials and Methods

2.1.1. Subject Description

This study was performed on a single subject, also co-author of this manuscript, Christophe Rocher (CR), 53 years old. CR started playing the clarinets at the age of 7, and plays both the clarinet and the bass clarinet. CR has performed regularly in regional, national and international music scenes, in particular in the free improvisation scene, with ensembles of various sizes, as well as in performances with other artists such as dancers or spoken word artists. Importantly, the present study involves CR more than as a mere participation as a musician; we setup a collaboration with CR in order to define an appropriate approach to study musical improvisation from the point of view of an improviser. This collaboration was kept all along the project, but its goal was to assist on the definition of the main paradigm. As a consequence, the data collection performed in this study was agreed upon with CR in the preliminary phase of the study. An informed consent form was signed so that CR was aware of what kind of data we were going to collect (EEG and audio), that he could decide to withdraw at any time, and that he could ask that his data was deleted at any time.

2.1.2. Preliminary Phase

We aimed at defining an ecological paradigm to study improvisation, with two aims. First, we tried to approach improvisation from the point of view of CR. The point made here consists in examining in detail the strategies developed by one particular improviser during his career, and document closely his creative process. Second, we target the study of subjective mental states associated with his performance. The proposed approach attempts at studying improvisation using a bottom-up approach, starting from the subjective experience of the improviser and in an ecological manner.

Experimental sessions consisted of free improvised concerts with an audience, followed by a relistening session. The goal of the relistening session was for CR to attempt a retrospective mental replay of his subjective experience during the performance. We aimed at documenting this retrospective phase. In preliminary experiments taking the form of private rehearsals, CR made an open commentary while listening to the performance. A first informal discussion around the content of these commentaries has enabled us to consider several emerging concepts : focus on improvisation, flow, satisfaction about the music being played, and the relationship between the musicians and subjective time perception. According to CR, these concepts were the ones that forge his everyday practice, and are related to the musical and personal objective occurring during a performance with an audience. At this stage in the project, we identified and acknowledged two important limitations in our approach. First, we were aware of the idiosyncrasies of these concepts, which may or may not apply to other professional improvisers. Second, as the open commentary of CR of his improvised performances tended to lean toward the same concepts, we decided to attempt a quantification of these concepts, by performing a continuous rating with three factors while listening to the performance.

Six rehearsals were performed in total, which are considered as the pilot phase of the project. During the first rehearsal, the retrospective phase consisted of the open commentary described above. During the second and third rehearsal, we asked CR to annotate the performance using a continuous rating with three factors. We agreed with CR on the meaning of the extreme values of these factors, and debriefed after each annotation session to make sure that the annotation were performed consistently.

The first factor was “focus,” and corresponds to how much CR felt he was successfully focused on improvising. A high value in Focus meant that CR was improvising while not being distracted. A low value meant that the focus on improvisation was compromised for various reasons. These reasons can relate to sonic or technical aspects of playing such as being in tune, having a nice clarinet sound, breathing. CR also reported higher level cognitive distractions related to the audience or music unrelated mind-wandering, in which case he also put a low value for focus. The second factor was "Subjective Temporal Resolution" (STR), corresponding to variability in the subjective quantization of time as retrospectively assessed by CR. According to CR, such a subjective quantization influences how he reacts to the music being played by other musicians, and can be loosely related to a subjective musical *tempo* (while the music itself often doesn’t have a clear tempo), or a clock with a period of a few 100 ms up to a few seconds. Note that while STR is linked to the speed of subjective time, CR claims that it does not necessarily correspond to the speed of notes that he is currently playing, if he is playing at all, and we specifically tested this hypothesis (see section 2.3.4). CR reported that he consistently set low (respectively high) values of STR when his subjective quantization is slow (respectively fast). The third factor was “quality,” related to the personal satisfaction about the music being played. This factor judged *a posteriori* the quality of the music, from the point of view of CR, in terms of whether it corresponds to what he expects to offer to the audience.

These three factors were used for annotating the second and third rehearsal. The performances were annotated just after being played. A debriefing at the end of the third rehearsal was done and we agreed with CR that the third factor, “quality,” was most of the time highly correlated with “focus,” and it was also challenging to annotate three factors simultaneously and continuously while listening. We therefore decided to drop the “quality” factor. The three other rehearsals were used for piloting the EEG recording, getting familiar with playing with

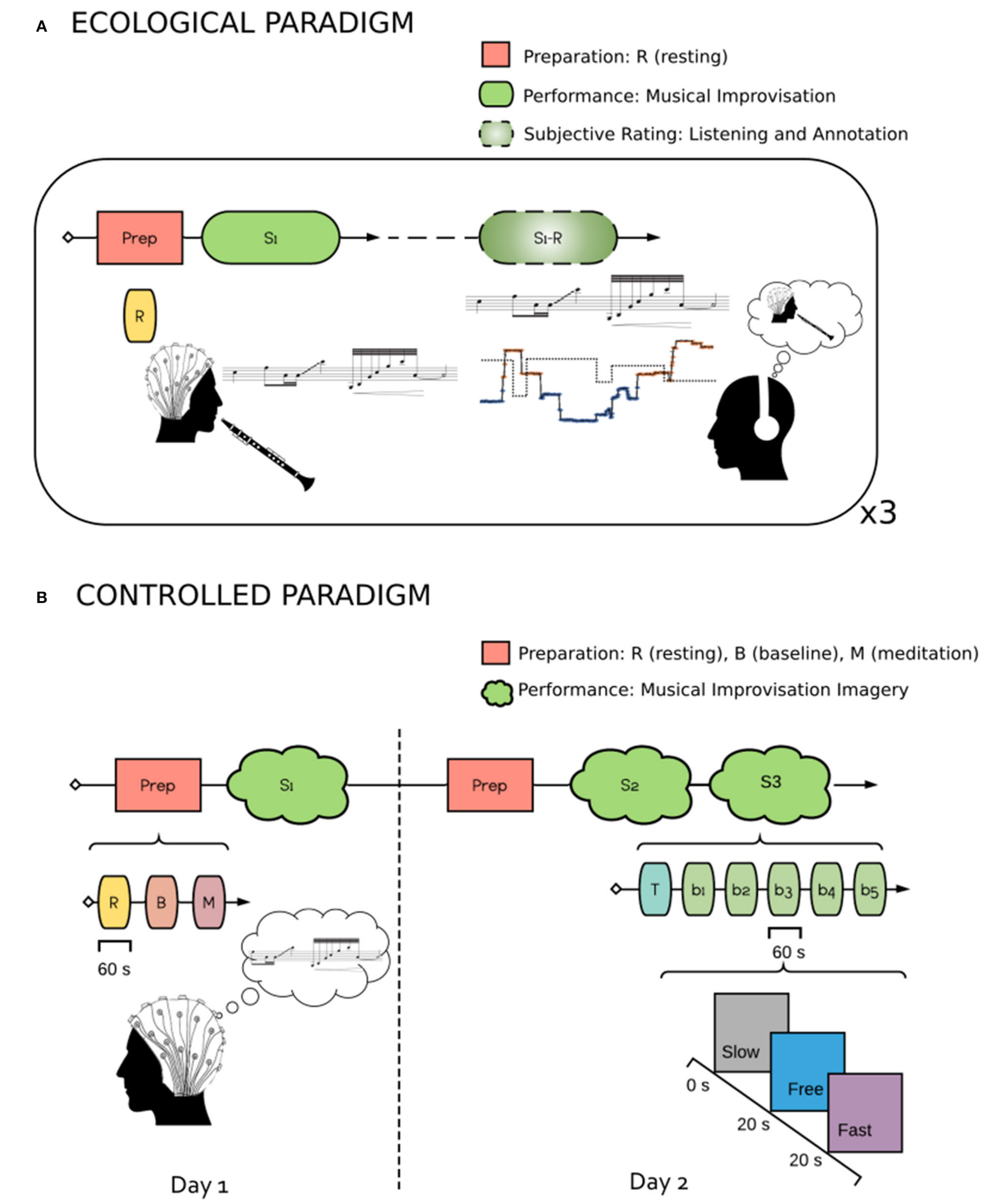

FIGURE 1 | Experimental Protocols Schematics. **(A)** ecological Paradigm. The experiment included two parts. In the first, EEG was recorded while the subject performed musical improvisation. In the second part, the subject listened to his own performance and performed the retrospective rating using the two factors Focus and STR, detailed in section 2.1.2. **(B)** controlled Paradigm. The experiment was carried out in 2 days. In the first, the subject underwent a preparation session where he performed 60 s of Resting (Eyes Opened), 60 s of Baseline and 60 s of Meditation. He then performed a musical improvisation imagery task with a Slow, Fast or Free conditions. The second part (2 days later) was as the first, with the exception that two training sessions were performed.

the EEG device while minimizing head or eye movements. We also performed these last rehearsals with a very limited audience (1–2 people) in order to have people actually listening, which according to CR helped him to be in a state closer to an actual performance.

2.2. Procedure

2.2.1. Ecological Paradigm

Here, we describe the final ecological setting that was used for the three public performances considered in this paper. Two performances took place in March 2019 in Brest, France, in front of audiences of 50 people (referred to as performance 1 and performance 2 in the rest of this paper). The third performance (performance 3) took place in Montreal at the Montreal Neurological Institute in June 2019. Each performance was scheduled to last 20 min maximum, and the aim was to break it into two sessions of 10 min. The performances were followed by a 20 min long talk and a discussion, presenting the project aims, and involving CR in the discussion with the audience. Following a preliminary recording session where we qualitatively assessed the impacts of blinks, eye movements and movement artifacts while recording and after recording, we discussed how to reduce them during the performance. It was agreed that CR would keep his eyes closed and that he would make his best to limit his movements (i.e., body, fingers, breathing,…). A video of performance 3 can be found here https://www.youtube.com/watch?v=ILhaZYtW8fs, as well as a short documentary (in french) with excerpts of rehearsals and of performances 1 and 2, here https://www.kubweb.media/page/nautilis-neurosciences-jazz-improvisation-nicolas-farrugia/.

2.2.2. Data Acquisition

Each session was structured in the following way (**Figure 1A**). CR played pieces in duet or trio lasting approximately 10 min. During each piece, we recorded audio and electroencephalography (EEG) on CR. Audio was recorded using a RME Fireface 400 FireWire audio interface, with two Neumann KM184 microphones. Microphones were placed to record the whole band for the subsequent relistening phase. The Bitwig software was used for the recording. EEG was acquired using an open BCI 8 channel Cyton amplifier. We used the headband kit to measure three frontal flat snap electrodes positioned on Fpz, Fp2 and Fp1, as well as two temporal dry comb electrodes located at FT7 and FT8. EEG was recorded at a sample rate of 250 Hz using the Fieldtrip buffer (Oostenveld et al., 2011) and the EEG synth software (https://github.com/eegsynth/eegsynth). A 1 min resting state was acquired, during which CR relaxed and prepared himself silently. This 1 min performance 2 resting state was part of the public performance and served as a silent introduction. CR was deliberately instructed to keep his eyes closed during the performances. Following each piece, CR listened back to the audio recording (no later than 24 h following the performance), and performed the retrospective rating using the two factors Focus and STR, detailed in section 2.1.2. Retrospective rating was acquired using the Bitwig software using a USB-MIDI control interface with two continuous sliders.

2.3. Data Analysis

2.3.1. Behavioral Data Analysis

A qualitative analysis of the values taken by Focus, suggested that the Focus rating was generally high during performance (**Figure 2**, right panel). Discussions with CR have led us to consider that Focus did not represent a source of variability inherent to musical improvisation, but rather was indicative of whether he reached the target state enabling him to improvise. As a consequence, in the rest of our analysis, we will only consider the STR rating. We used Hidden Markov Models (HMM) (Rabiner, 1989) to quantify the STR time series into discrete states. HMM is a probabilistic sequence model that estimates a series of *hidden states* from a set of observations. These hidden states are interpretable as causal factors of the probabilistic model (e.g., subjective "states" of STR). We considered a HMM with Gaussian emissions with two hidden states corresponding to *low* and *high* values of STR. We used the hmmlearn package (https://hmmlearn.readthedocs.io/en/latest/index.html) to learn the HMM model solving the iterative Baum-Welch Expectation-Maximization algorithm (Dempster et al., 1997).

2.3.2. EEG Preprocessing

EEG data were preprocessed using the MNE-python toolbox (Gramfort et al., 2013). First, signals were bandpassed filtered with a FIR (Finite Impulse Response) filter in the 1–40 Hz frequency band. To reduce eye movement artifacts, we perform Independent Component Analysis (ICA) using the *fastica* algorithm (Hyvarinen, 1999) applied to continuous data. We ran an autodetection algorithm to find the independent component that best matched the "EOG" channel (prefrontal electrode Fp2). ICA components that strongly correlate with the EOG signal were then removed (adaptive Z-score threshold = 1.6) and the EEG signal was reconstructed with the remaining components. In order to reject residual movement artifacts, we then segmented data into consecutive epochs of 3 s and remove those in which the signal amplitude of one or more channels exceeded a threshold set to keep the 85% of recordings.

2.3.3. Time-Frequency Analysis and Decoding Model

We performed a time-frequency analysis using multitaper filters to estimate the EEG power spectral density and the average power in different frequency bands (theta, alpha and beta) computed with reference to the individual alpha frequency (Babiloni et al., 2010) of the subject (IAF = 9.3 Hz). Based on IAF frequency we estimated the theta, alpha and beta bands, respectively equal to [4.5–7.5] Hz, [7.5–11.5] Hz, and [11.5–25] Hz. We estimated the EEG power for 3 s epochs and assessed whether it could predict the STR as being *low* or *high* using a decoding model with a Support Vector Classifier (SVC) and a radial basis function kernel with regularization ($C = 1$, penalty on the squared l_2 norm), implemented in the scikit-learn package (Pedregosa et al., 2011). In order to test for within-sample generalization of our decoding model using the data at hand, we used a stratified K-fold cross-validation with 4 folds in order to consider the same percentage of samples of each class per fold. We measured classification accuracy and

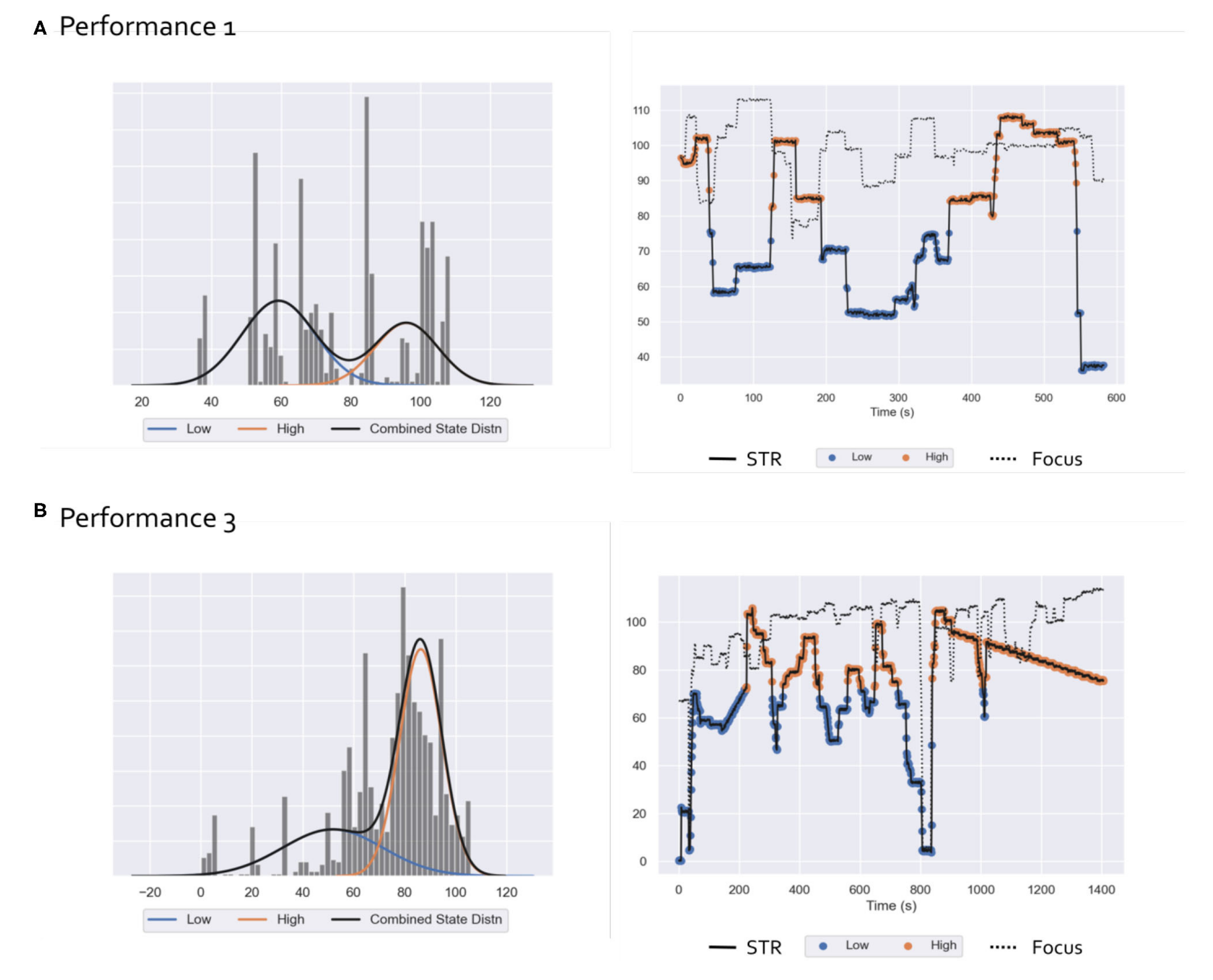

FIGURE 2 | Ecological Paradigm: Results of HMM analysis of subjective rating scores for performance 1 **(A)** and performance 3 **(B)** Left: STR samples histograms and distribution (black) as a mixture of low (blue) and high (orange) states Gaussian distributions. Right: STR (solid line) and Focus (dotted line) time-series relative to the performances 1 and 3. For the STR, samples corresponding to the low and high states are labeled with blue and orange markers, respectively.

f1-score for each class and fold. In order to provide an even more conservative robustness assessment of our results, we performed a hundred repetitions of the same cross-validated SVC training using random permutations of class labels (see https://scikit-learn.org/stable/modules/generated/sklearn.model_selection.permutation_test_score.html). This permutation test score provides an estimation of the chance level of our decoding model according to the variance in the dataset. We performed a *post-hoc* univariate statistical inference analysis by investigating changes in the different frequency bands related to the STR state. More specifically, we assessed differences between average EEG power during low and high states in the theta, alpha and beta bands by means of a pair-wise two-sided Welch *t*-test.

2.3.4. Audio Analysis

The aim of the audio analysis was to characterize note density (number of notes played every second) and volume of the musical performance of CR on the three performances, in order to study their relationship with Subjective Time Resolution (STR) and EEG rhythms. This analysis was performed separately for each performance. First, we separated the different musical instruments recording before counting notes. For each performance there were three instruments: clarinet (CR), drums and double bass for the first two performances and clarinet, double bass and trumpet for the third performance. As we are focusing on the performance of CR (specifically, the number of notes he played) we separated the clarinet from the two other instruments. We used the 4 stem source separation pretrained model from the library Spleeter (Stöter et al., 2018; Hennequin et al., 2020) developed and open-sourced by Deezer. Spleeter allowed us to split music instruments leveraging pre-trained neural networks implemented in TensorFlow. Next, note onset detection was performed on the clarinet track separated during step 1. For this, we used an onset detection method available in the librosa package (https://librosa.org/doc/main/generated/librosa.onset.onset_detect.html#librosa.onset.onset_detect) that works by detecting local peaks in the envelope strength, using hyperparameters set on a large music database. We validated note density extraction qualitatively by retrieving several samples for each note density bin and checked qualitatively if the note density was well estimated. Then, we assessed the link between note density during the musical performance and subjective state (STR). First, we estimated the distribution of note density values across performances. As there are many moments during which CR does not play, we get an important proportion of note density values of 0. However, non-zero density values followed an approximately gaussian distribution, that we binned in three equally spaced intervals based on non-zero note density value histograms (low, medium and high density, see **Supplementary Figures 1, 2**). We tested the hypothesis whether CR plays more notes per second as a function of subjective state (high or low STR), by using the annotations of the HMM (see behavioral data analysis) and performing a Welch's t-test on non-zero note density distributions. We also compared qualitatively the count of note densities equal to zero (i.e., moments during which CR does not play for 1 s) in the subjective states. We also tested the hypothesis that the volume of musical performance was related to subjective state. To this end we calculated the RMS energy of each performance using the librosa function librosa.rms() and compared RMS distributions for low and high STR using Welch's t-test.

Finally, to test whether audio features had a significant impact on EEG power in different frequency bands, we first used Spearman correlation to test whether power in each frequency band was related to RMS volume. Next, we tested for associations between EEG power in each band and note density using a Kruskal Wallis Anova with the four abovementioned categories: silence (note density equal to zero), low density, medium density and high density. When relevant, we performed *post-hoc* tests for pairwise differences using Welsch' t-tests.

All statistical analysis presented in this manuscript were performed using the stats module of scipy (https://docs.scipy.org/doc/scipy/reference/stats.html#module-scipy.stats), as well as scikit-posthocs for *post-hoc* tests (https://scikit-posthocs.readthedocs.io/en/latest/). Supervised learning and statistical inference on the decoding models was performed with sklearn Pedregosa et al. (2011). We report raw p-values everywhere possible, considering a significance threshold of $\alpha = 0.05$.

2.4. Results

2.4.1. Analysis of Subjective Ratings

Results of the HMM analysis of STR time-series for performances 1 and 3 are reported in **Figure 2**. Two hidden states corresponding to low and high STR values were identified: the relative estimated Gaussian distributions are represented in the left panels of **Figure 2** while their values during the performance, together with the Focus index trends are reported in the right panels. EEG recordings of performance 1 were highly contaminated by environmental and movement artifacts (see EEG results section). Since we only examined behavioral indexes relative to preprocessed EEG epochs, the number of samples of STR and Focus for performance 1 is drastically reduced as compared to performance 3, resulting in a sparser histogram distribution and shorter time-series.

We note that Focus values are generally staying high during performance, with a few disrupted moments occurring with low values. As a consequence, we did not model the variability in Focus, and the rest of the analysis was performed with respect to HMM states obtained by the analysis of STR values.

2.4.2. Link Between Subjective States and Audio-Derived Features

We first sought to test whether the identified subjective states (low and high STR) were related to the volume of the overall performance. RMS energy (volume) was lower in the low STR state than in the high STR state for performance 2 [$t_{(1,046)} = -7.7$, $p =$ 1e-14], while it was higher in low STR than in high STR state for performance 1 [$t_{(581)} = 7.0$, $p =$ 5e-12] and performance 3 [$t_{(1,045)} = 10.9$, $p =$ 1e-26]. Next, we analyzed the note count played by CR per second (note density) as a function of subjective state. We found quantitative differences when examining moments during which CR does not play (approximated by a note density of zero, meaning no note played for 1 s), with a lower number of zero densities in low STR compared with high STR in performance 3 (3 for low STR, 29 for high STR), while the opposite was true for performance 1 (47 for low STR, 16 for high STR) and performance 2 (104 for low STR, 54 for high STR). Finally, slightly more notes per second were played in low STR than in high STR for performance 2 [mean density for low STR = 11.1 note per second, 9.8 for high STR, $t_{(888)} = 5.7$, $p =$ 1e-8] and performance 3 [mean density for low STR = 10.3 note per second, 9.4 for high STR, $t_{(1,367)} = 4.8$, $p =$ 1e-6 but no difference was found in performance 1 [mean density for low STR = 8.7 note per second, 8.6 for high STR, $t_{(518)} = -0.4$, $p = 0.7$]. A graphical depiction of those results for performances 1 and 3 is given in **Supplementary Figures 1A, 2A**.

2.4.3. Link Between EEG Oscillatory Power and STR

A hardware problem with the EEG amplifier occured when recording performance 2, so we only report results on performance 1 and performance 3. The EEG recordings of performance 1 being very noisy, only the equivalent of 10 min recordings survived artifact rejection and were considered for further analysis. For performance 1, SVC results indicated that high and low STR states could be classified with an average accuracy of 0.69 ± 0.11 (standard deviation across folds) (f1-score high 0.63 ± 0.16–94 examples-, f1-score low 0.74 ± 0.10–87 examples-). Similarly for performance 3, a SVC trained on EEG power distinguished low from high states with an average accuracy of 0.69 ± 0.11 (f1-score high 0.69 ± 0.16–165 examples-, f1-score low 0.66 ± 0.12–170 examples-). The permutation test in both cases indicated that the decoding model performed significantly better than chance ($p < 0.01$).

Post-hoc statistical analysis (**Figure 3**) for the different frequency bands revealed that theta, and beta average power was higher in the high STR state condition as compared to the low condition both in performance 1 [theta: $p =$ 2.5e-08,

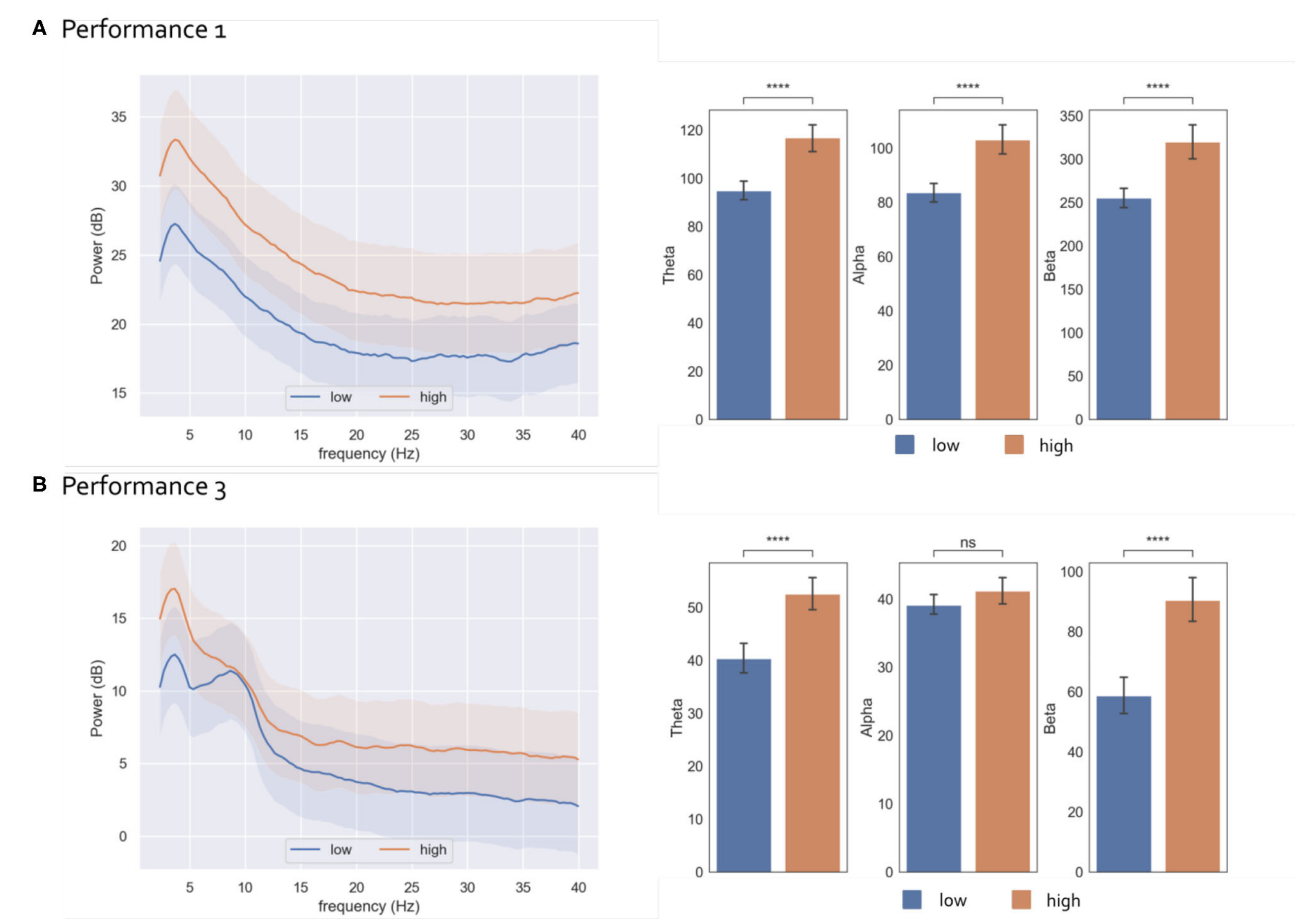

FIGURE 3 | Ecological Paradigm: Results of EEG *post-hoc* frequency analysis in relation to STR for performance 1 **(A)** and performance 3 **(B)** Results represent EEG power averaged across electrodes. Left: EEG Power Spectral Density (mean across 3 s epochs) corresponding to low (blue) and high (orange) states, with 95% confidence intervals. Right: Bar plots representing the EEG power (mean ± std) in the Theta, Alpha and Beta bands in low and high states. Square brackets indicate significant differences as assessed with pair-wise two-sided Welch *t*-test (****$p < 0.00001$).

$t_{(155)} = -6.30$; beta: $p = 6.4e\text{-}07$, $t_{(19)} = -5.69$] and performance 3 [theta: $p = 3.1e\text{-}06$, $t_{(239)} = -5.24$; beta: $p = 1.9e\text{-}05$, $t_{(226)} = -4.8$]. This trend was also observed in the Alpha band for performance 1 [$p = 1.8e\text{-}07$, $t_{(154)} = -5.91$] but was not significant in performance 3 [$p = 7.8e\text{-}01$, $t_{(201)} = -1.7$].

2.4.4. Link Between EEG Oscillatory Power and Audio-Derived Features

The volume of performance 1 was positively correlated with theta power ($\rho = 0.2$, $p = 0.03$), but not with alpha ($\rho = 0.09$, $p = 0.3$) and marginally with beta power ($\rho = 0.2$, $p = 0.07$). Interestingly, the opposite relationship was found for performance 3, with volume being negatively correlated with alpha power ($\rho = -0.2$, $p = 0.007$), beta power ($\rho = -0.2$, $p = 4e\text{-}4$) and theta power ($\rho = -0.3$, $p = 1e\text{-}5$). We subsequently tested for associations between note density and EEG power, by using four bins of note density (zero, low, medium, and high) in separate Kruskal Wallis tests for each frequency band. In performance 1, we found a significant effect of note density on alpha power ($t = 9.5$, $p = 0.02$), beta power ($t = 9.2$, $p = 0.02$) and theta power ($t = 11.3$, $p = 0.01$). A similar pattern of results was obtained for performance 3, with an effect of note density on alpha power ($t = 11.6$, $p = 0.001$), beta power ($t = 8.8$, $p = 0.03$) and theta power ($t = 10.8$, $p = 0.01$). In performance 3, *post-hoc* *t*-test revealed higher EEG power during zero note densities than during the three other levels of note density, with the largest effect obtained in the three frequency bands (all comparisons between zero density and other levels with $p < 0.01$). In performance 1, lower alpha and beta power was observed during zero note density than during medium note density ($p < 0.05$). Lower theta power was also observed during zero density than during low ($p = 0.004$), medium ($p = 0.003$) and high ($p = 0.04$) densities. These results are illustrated in **Supplementary Figures 1B, 2B**.

3. EXPERIMENT 2 : CONTROLLED PARADIGM

3.1. Materials and Methods

3.1.1. Procedure

The experimental paradigm is described in **Figure 1B**. The main goal of this experiment is to manipulate STR in a controlled setting, by asking CR to perform a musical improvisation imagery task, while constraining himself to stay in a particular state with respect to STR, thus corresponding to different quantization of subjective time. Three conditions were considered : Slow, Fast and Free. Slow and Fast corresponded, respectively, to slow or fast quantization of subjective time. These conditions are considered according to the states found when analyzing the retrospective rating phase of Experiment 1 (see sections 2.1.2, 2.4.1). For these two conditions, the instructions given to CR were to imagine he was improvising while keeping a subjective state that he would have rated as either Low or High STR during the retrospective phase. The third condition, Free, corresponded to musical improvisation imagery without constraints on a subjective state related to STR. The experiment was carried out over two separate sessions on two different days. During each session, we performed a preparation phase which consisted of a 1-min long resting state with eyes open (R), a 1-min active baseline consisting in counting backwards (B), and a 1-min meditation phase (M) during which CR attempted to focus on breathing. In both B and M phases CR kept his eyes closed. These conditions were implemented in order to have clear cut comparisons between states with different mental workload in order to check signal quality, and were not analyzed further (except for the B condition which was used to determine IAF). Following the preparation phase was the musical improvisation imagery task. The experiment was organized into a training block, followed by 5 musical imagery blocks. The order of conditions was randomized and counterbalanced across blocks, and each condition was presented fifteen times in total. Each block consisted of three consecutive trials of 20 s. Instructions were given vocally at the beginning of each trial, with the experimenter pronouncing the words "Slow." "Fast," or "Free." These instructions were explained before the training block. A debriefing after the practice block of each session was made, in order to gather informal feedback on the feasibility of the task. Within a block, a condition might be repeated, in order to avoid that CR predicts the third condition and change his strategy accordingly. A short break was done after each block. During the first session, we performed only five blocks, while two times five blocks were done during the second session, with a longer break between after the fifth block.

3.1.2. EEG Acquisition

The measurements were done in two slightly different settings for day 1 and day 2. During day 1, we performed the experiment in a moderately quiet environment, a common space with a few people passing. During day 2, we performed experiments in a quiet room with only the experimenter and CR. As for the ecological paradigm, at the beginning of each session CR was given precise instructions to keep his eyes closed during musical imagery. CR performed all the conditions while closing his eyes, and could open his eyes between blocks. CR was sitting in front of a white wall with the experimenter in his back. EEG was acquired using the same amplifier and software setup than in Experiment 1 (see section 2.2.2), but with a different electrode montage. Four goldcup electrodes were positioned at O4, P4, C4 and Fp4 using conductive paste.

3.2. Data Analysis

3.2.1. EEG Preprocessing

As for the first experiment, we performed ICA on the band-pass filtered EEG signals (1.0–40.0 Hz) in order to reduce eye movements artifacts using the prefrontal electrode Fp2 as a proxy for the EOG channel. We then divided each block into 20 s segments according to the trial onsets, and removed the first 5 s of each trial to reduce the effect of transition between trials. Finally, trials were segmented into consecutive epochs of 3 s, and epochs in which the signal amplitude of one or more channels was high were removed, using a threshold set to keep 90% of data.

3.2.2. Statistical Analysis

Individual Alpha Frequency (IAF) (Babiloni et al., 2010) was determined by finding the individual dominant EEG frequency in the baseline signal. As for the first experiment the resulting frequency bands were: theta [4.5–7.5] Hz, alpha [7.5–11.5] Hz, and beta [11.5–25] Hz. To conduct our analysis, we estimated the average power spectral density across the four electrodes (Fp2,C4, P4, O2) using multitaper filters, and we computed the power in the different frequency bands. The 3 s-long epochs were labeled with the corresponding condition (free, slow, and fast) and Welch pair-wise *t*-tests were performed to assess the effect of condition on the EEG power magnitude in different frequency bands of interest. Results were corrected for multiple comparison according to the Bonferroni correction.

3.3. Results

3.3.1. Behavioral Results

CR indicated that he could generally perform the task, and gave details about specific mental imagery strategies that he used to help him perform the task correctly. CR indicated that he imagined himself playing in specific places, with specific people. As a consequence, the feedback given by CR suggest that he engaged more than in a constrained mental imagery exercise.

3.3.2. EEG Results

Statistical analysis results (**Figure 4**) revealed that beta power was higher in the Slow condition as compared to the Fast condition [$p = 0.049$, $t_{(116)} = 2.83$]. The Free condition was associated with a higher beta [$p = 0.011$, $t_{(119)} = 3.31$] and theta power [$p = 0.008$, $t_{(134)} = -3.41$] if compared with the Fast condition. This trend was also observed in the Alpha band but did not survive Bonferroni correction.

4. DISCUSSION

4.1. Summary

We have presented an ecological paradigm of musical improvisation live performance with an audience, consisting in EEG measurements of an improviser, followed by a listening phase with retrospective rating. The objective of the rating was to perform *a posteriori* mental replay of the subjective state of the performer. A discussion with the improviser led us to consider two continuous factors when rating performance: Focus

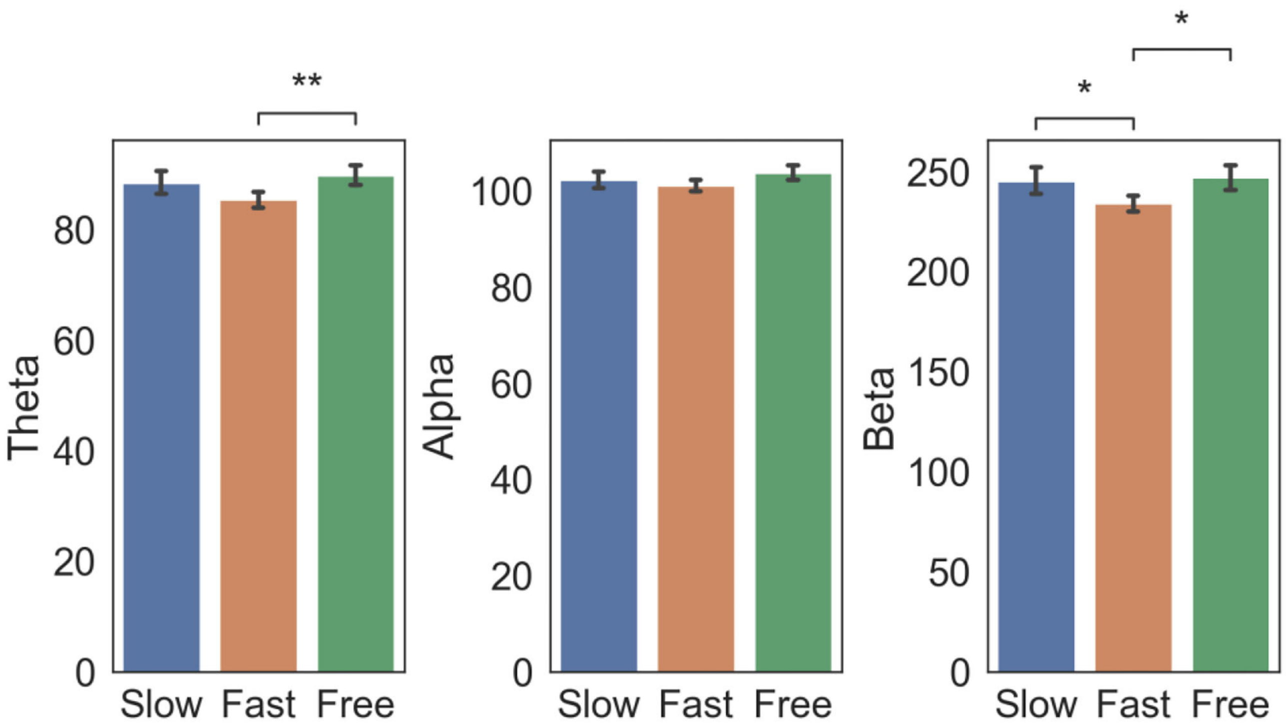

FIGURE 4 | Controlled paradigm: EEG power changes as a function of subjective time condition. EEG power (mean ± std across electrodes Fp2, C4, P4, and O2) in the Theta, Alpha and Beta bands in epochs corresponding to Slow, Fast and Free condition. Square brackets indicate significant differences as assessed with pair-wise Welch *t*-test (*$p < 0.05$, **$p < 0.01$, Bonferroni corrected).

and Subjective Temporal Resolution (STR). The meaning of these factors was discussed, piloted and consistently confirmed with the subject. Focus measured a general tendency to "feel in the music," or "being in the zone." STR measured subjective temporal resolution, which indicates whether the improviser was in a state of slow or fast subjective time quantization. Using a decoding model trained on EEG power during performance, we found that states of high and low STR could be reliably distinguished, and were related to increases in average theta and beta power during the high STR state. We also showed that CR played more notes in states of low STR than in states in high STR, in performances 2 and 3, and that states of low STR could be associated with higher volume (resp. lower volume) than states of high STR in performances 1 and 3 (resp. performance 2). When testing for associations between EEG power and number of notes played, we found global changes in power when CR plays compared to when he does not, but the number of notes played did not influence EEG power. We also found that EEG power was weakly correlated with volume in performance 1, and negatively correlated with volume in performance 3. In a second experiment in a controlled setting, we designed a musical improvisation imagery experiment targeted at testing differences in brain oscillations with respect to STR, and we found elevated EEG power in the beta band when CR was in a subjective state of low STR.

4.2. Musical Improvisation as a Target Subjective State?

We approached the question of characterizing improvisation as a target subjective state, measured by two factors in a retrospective rating. The concept of musical improvisation as a subjective state was previously proposed (Lopata et al., 2017; Dolan et al., 2018), and was interpreted in the context of flow state (Csikszentmihalyi, 1975). In the following, we attempt to interpret the two factors we measured, Focus and STR.

What we have termed Focus in this study corresponds to a component of a common definition of flow state, "the holistic sensation that people feel when they act with total involvement," (Csikszentmihalyi, 1975), and has been extensively studied, including in the music improvisation literature (e.g., see Chirico et al., 2015; Dolan et al., 2018; Luft et al., 2018; Tan and Sin, 2019). Previous research on flow state during improvisation was mostly done using interviews and observations (Tan and Sin, 2019). In our case, a qualitative analysis of the values taken by the Focus rating, together with informal observations discussed with the performer, suggested that Focus was generally staying high during musical improvisation performance, and corresponded to a target for appropriate performance. Preliminary exploratory correlation analysis between EEG power and the Focus factor did not reveal any link in our measurements.

On the contrary, STR, considered by CR as the quantization of subjective time, has not been previously documented as an aspect of flow state. Previous studies have proposed that the distortion of subjective time perception is an important part of the psychological state of flow (Csikszentmihalyi, 1975, 1990). Such an account usually refers to the feeling of an accelerated passing of time during flow state, and has been measured previously in laboratory conditions (Im and Varma, 2018), as well as in previous studies such as in gaming (Nuyens et al., 2019) and music performance (Chirico et al., 2015). To our knowledge, STR has not been a measure of interest in previous studies on flow state of musical improvisation. We therefore have to turn to the temporal processing and the attention literature to bring some light on our findings.

4.3. Subjective Temporal Resolution and Temporal Processing

Temporal resolution has been measured experimentally with simultaneity judgment tasks (Stone et al., 2001), in particular audiovisual simultaneity. Recent reviews have shown considerable variation in task performance according to stimulus modality, inter-individual differences, age, as well as subjective states (Arstila and Lloyd, 2014; Wykowska and Arstila, 2014). Interestingly, musical training has been shown to influence audiovisual simultaneity judgments (Jicol et al., 2018), suggesting that long-term training modulate musician's ability to integrate audiovisual information concurrently. Recently, audiovisual simultaneity has been linked to phase resetting in the EEG beta band (Kambe et al., 2015). However, we cannot comment on whether such integration processes are related to our findings on STR, as simultaneity judgments can only be done in lab settings with controlled stimuli. Another account related to temporal resolution is the concept of temporal receptive windows (Lerner et al., 2011), with a hierarchy spanning from early auditory cortices at the smallest time scales (<1 s), up to parietal and frontal areas for the largest ones (up to a minute). Here, our attempt at measuring STR had the objective of tapping into subjective processes related to the quantization of subjective time. While a very large body of literature exists on subjective timing paced by an internal clock with periods from seconds to minutes (as initially proposed by Church, 1984, see Allman et al., 2014 for a recent review), we are interested here in shorter periods in the range of a few 100 ms up to a few seconds. Such short time scales have been tackled in studies on the neural basis of temporal processing.

4.4. Brain Oscillations and Subjective Temporal Resolution

The proposed STR measure as well as our EEG results may also be interpreted with regards to a large body of work on electrophysiological correlates of temporal processing (Macar and Vidal, 2004; Wiener and Kanai, 2016), in light of predictive processes (such as isochronous sounds or beat perception), duration estimation and attention to temporal events (Nobre and Van Ede, 2018). We note first that no single EEG frequency band has been dominantly associated with temporal processing, as comprehensively shown in the cross-study review by Wiener and Kanai (2016). More specific effects have been suggested in different types of paradigm. First, it has been shown that temporal expectations may modulate power in the theta band, as well as the coupling between theta phase and beta power (Cravo et al., 2011), which could indicate the existence of a central mechanism for controlling neural excitability according to temporal expectations. These results have been recently complemented by a study that combined electrical stimulation and reanalysis of previous EEG data, showing an intrinsic role of beta oscillations in the memory of temporal duration (Wiener et al., 2018). The beta band has also been associated with effects of temporal prediction in the case of beat-based timing in perception (Fujioka et al., 2012) and imagery (Fujioka et al., 2015). Finally, a classical paradigm to study temporal attention consists in providing a cue that predicts (or not) a short or long foreperiod between a warning stimulus and an imperative stimulus requiring a motor response. This paradigm revealed shorter reaction times when the cue successfully predicts the length of the foreperiod, together with an increases amplitude of the Contingent Negative Variation (Miniussi et al., 1999), as well as an increased EEG power between 6 and 8 Hz for stimuli with short foreperiods compared to long ones (Babiloni et al., 2004). These results suggests that the brain allocates a temporal attention window of variable length mediated by underlying oscillatory mechanisms, namely the magnitude of EEG power in the 6–8 Hz band (upper theta band).

In experiment 1, we found a higher power in low frequency oscillations (4.5–7.5 Hz, dubbed theta in our study) and beta band (11.5–25 Hz) with high STR compared to low STR. As we are associating a retrospective subjective rating with EEG acquired in the presence of noise and movement, we attempted at disentangling the effect of overall volume and quantity of motor commands (approximated by a measure of note count per second) on the measured EEG. In performance 1, we found a weak correlation between theta power and volume, as well as a global increase in EEG power when CR plays compared to when he doesn't. The opposite pattern was found in performance 3, with a negative correlation between volume and EEG power, as well as a global reduction of EEG power when CR plays. However, in both performances, the number of notes played did not influence EEG power. Importantly, we also showed using audio analysis of performances 1 and 3 that high STR was associated with lower note counts and higher volume than low STR. Therefore, it is unlikely that the EEG modulations we observed with respect to STR are solely due to motor activity, as otherwise we may expect to observe a relationship between EEG power and note count. Finally, we remark that the effect of STR on EEG power was consistent in both performances. This suggests that STR as measured in this ecological paradigm might reflect an underlying endogenous timing mechanism that calibrates the duration of a temporal window of integration, or equivalently, the rate of a sampling mechanism involved in musical performance and perception. This interpretation would fit with the description of the behavioral relevance of STR as discussed with CR during the definition of the protocol. It is obviously difficult to compare the ecological paradigm of experiment 1 with controlled experiments such as the ones mentioned previously, as we do not have controlled stimuli and multiple repetitions. The choice of performing a first experiment in an ecological setting was essential to define behavioral indexes related to the subjective experience of the musician, but came with some drawbacks. The main one is the limited quality of EEG signals collected in an environment exposed to noise and while CR was performing (e.g., freely moving). This compromised EEG recording during perf 2 and affected perf 1 signal quality. These limitations also motivated us to perform a second study in a controlled setting, where we could experimentally manipulate the subjective time state and assess STR changes on good-quality EEG recordings. As a consequence, we attempted to test specifically the effect of varying the rate of this sampling mechanism by defined a controlled paradigm. In experiment 2, we instructed the subject to perform musical improvisation imagery while keeping a specific state of STR. In a third condition, no constraint was given and the subject could perform imagery without keeping a constant STR state. We found an elevated theta and beta power when comparing the Free (unconstrained) condition with the Fast condition (corresponding to a high STR state), as well as higher beta power for Slow compared to Fast. While it can seem surprising to find a reverse effect than in experiment 1, it is difficult to conclude as theta and beta power was overall higher in the Free condition, which is the one that is closer to the ecological paradigm. Nevertheless, our results suggest that oscillatory power in the theta and beta band is correlated with an internal, subjective temporal processing system related to STR.

4.5. Brain Oscillations and Flow State in Musical Improvisation

A qualitative analysis of our ecological paradigm led us to consider the first rating, Focus, as an indicator of flow state during improvisation. We did not find any statistical association between the values of Focus and EEG power spectrum. However, in experiment 2, we did find a higher power in the theta and beta band when comparing the Free condition with the Fast condition. In this experiment, the Free condition corresponded to an unconstrained, more natural situation with respect to experiment 1, in contrast with the Slow and Fast conditions that instructed CR to perform mental imagery of a specific STR state. Therefore, the power increase observed in the Free condition may be interpreted in light of previous findings that showed EEG activity increases when comparing improvisation with "non-improvisation" (Boasen et al., 2018; Sasaki et al., 2019). Note however that the observed power increase might also be interpreted in a more general framework of creativity and flow state. Several studies have suggested a correlation between alpha-band activity and creative tasks (Stevens and Zabelina, 2019). Generally, it has been observed that tasks requiring greater creativity resulted in higher alpha power (Fink and Benedek, 2014). In particular, musical improvisation studies have reported higher alpha power in central and posterior regions of the brain, and a deactivation in prefrontal regions during the experience of flow (Dietrich and Kanso, 2010). Overall, the majority of the studies investigating creativity and musical improvisation report changes in alpha power, some studies even report clearer changes specifically in upper alpha (Boasen et al., 2018; Sasaki et al., 2019). In experiment 2, the power increase between Free and Fast was found in the upper frequency band [11.5–25] Hz, as we defined alpha as [7.5–11.5] Hz in which only a trend toward statistical significance could be observed. As a consequence we can situate our results among previous studies, while keeping it clear that we only considered one expert subject. This effect requires replication with a larger and more diverse sample, and could be the goal of future controlled studies attempting at examining musical improvisation or creativity using mental imagery.

4.6. Implications for the Artistic Endeavor

The proposed collaboration between arts and sciences represents an original contribution toward artists in terms of imagination, a resource for them to explore new ideas. Personal introspection in the form of retrospective ratings has the potential to give artists a special insight into creation and musical practice. Open questions arise with respect to understanding the link between subjective states and musical outcomes, and such an understanding could potentially enhance the creative process. Furthermore, the discovery of experimental research and neuroscientific methods could bring artists with several new insights. Such collaborations could help make the artists aware that the scientific view of artistic creation contribute to a better understanding of creativity (McPherson and Limb, 2013). Such an endeavor may challenge the place of the musician as part of a complex, dynamical system including the other musicians and the audience. This questioning is in line with recent accounts on understanding musical creativity using the embodiement framework and dynamical systems (Van der Schyff et al., 2018). Another contribution for artists is to learn about new technologies available today, with the idea of possibly directing musical and technological research toward the fabrication of new tools for musical computing, using for example neurofeedback or the sonification of brain waves. The wealth of research on brain computer interfaces, neurofeedback (Sitaram et al., 2017), and music information retrieval (Mueller et al., 2018), could potentially contribute to the future of musical creation.

4.7. Limitations and Perspectives

The limitations in this study are mostly inherent to the choices made regarding the ecological setting and the collaboration with a musician. As we considered a single subject, we do not have clear indications on the ability to generalize the concepts developed here and the findings to other musicians or other creative process. Future studies could attempt at testing hypothesis related to STR or flow in ecological settings using larger groups of musicians. In addition, while we decided early on to focus on a single subject, we relied only on retrospective reports and EEG recordings. The use of retrospective reports is limited by the metacognitive abilities of the rater, namely his ability to perform mental replay of the improvised performance. Such an ability might not be present with all musicians, which is another limitation toward a generalization of this procedure. Alternatively, future studies could consider semi-structured interviews in addition to retrospective ratings, which could potentially alleviate the bias introduced by ratings, while giving a richer qualitative view on the creative process, as done in previous musical improvisation studies (Tan and Sin, 2019). Another concern in our study is the lack of control for the content of musical imagery in experiment 2, in particular regarding the number of notes imagined. This could have an effect on resulting oscillatory power, and we plan to design future controlled experiments to try to disentangle imagined content and subjective state. Finally, as we measured brain activity on a single subject using EEG during musical performance, the measured signal is largely contaminated with movement artifacts and other sources of noise inherent to the ecological context. While we attempted at controlling for motor commands associated with clarinet playing by estimating note density, we cannot easily rule out the presence of other cognitive mechanisms, such as the attention to other players, auditory working memory, or simply cognitive load, that might influence the measured EEG in such a free, naturalistic setting. The setup used in this study is simple and lightweight, but it includes too few electrodes to enable a high resolution study of the complex mechanisms involved in naturalistic musical improvisation. Future studies could build upon this study, and attempt to measure brain activity in ecological settings with a higher resolution. In addition, one way to limit contamination by movement artifacts would be to consider using functional near infrared spectroscopy (fNIRS) and motion capture simultaneously with EEG in order to provide a complementary view on brain activity while accounting for movement.

4.8. Conclusion

In this study, we have setup a collaboration with an artist, CR, performing free musical improvisation. This collaboration has led us to define an ecological paradigm to study musical improvisation during live performances with audiences, using retrospective ratings and electroencephalography. We have suggested a measure of Subjective Temporal Resolution as a correlate of a subjective state related to the quantization of internal time of the improviser during performance, and were able to relate this measure to EEG oscillatory power in the theta/low alpha and beta band. We subsequently devised a controlled musical improvisation imagery experiment and found a relationship between constraints on subjective time and oscillatory power in the EEG. Our results bring an original perspective on the study of musical improvisation and creativity, by showing the potential of single subject studies and ecological paradigms.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The code and data for this study can be found at the following urls: for EEG analysis https://github.com/alixlam/Brainsongs1 and for audio analysis https://github.com/julesbouvet/Analysis_for_BrainSong.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participant provided its written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

NF and CR designed the study and ran the experiments. AL, GL, JB, and NF analyzed the data. All co-authors contributed to writing the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnins.2021.626723/full#supplementary-material

Supplementary Figure 1 | Audio Analysis results for performance 1. **(A)** Shows note density histograms for STR low (blue) and high (orange). **(B)** Reports EEG power changes as a function of the note density in the three frequency bands of interest (theta, alpha, beta).

Supplementary Figure 2 | Audio Analysis results for performance 3. **(A)** Shows note density histograms for STR low (blue) and high (orange). **(B)** Reports EEG power changes as a function of the note density in the three frequency bands of interest (theta, alpha, beta).

REFERENCES

Allman, M. J., Teki, S., Griffiths, T. D., and Meck, W. H. (2014). Properties of the internal clock: first-and second-order principles of subjective time. *Ann. Rev. Psychol.* 65, 743–771. doi: 10.1146/annurev-psych-010213-115117

Arstila, V., and Lloyd, D. (2014). *Subjective time: The Philosophy, Psychology, and Neuroscience of Temporality*. Cambridge, MA: MIT Press.

Babiloni, C., Miniussi, C., Babiloni, F., Carducci, F., Cincotti, F., Del Percio, C., et al. (2004). Sub-second "temporal attention" modulates alpha rhythms. a high-resolution eeg study. *Cogn. Brain Res.* 19, 259–268. doi: 10.1016/j.cogbrainres.2003.12.010

Babiloni, C., Pistoia, F., Sarà, M., Vecchio, F., Buffo, P., Conson, M., et al. (2010). Resting state eyes-closed cortical rhythms in patients with locked-in-syndrome: an eeg study. *Clin. Neurophysiol.* 121, 1816–1824. doi: 10.1016/j.clinph.2010.04.027

Bailey, D. (1982). *Musical Improvisation: Its Nature and Practice in Music*. New York, NY: Prentice Hall.

Barrett, K. C., Barrett, F. S., Jiradejvong, P., Rankin, S. K., Landau, A. T., and Limb, C. J. (2020). Classical creativity: a functional magnetic resonance imaging (fmri) investigation of pianist and improviser gabriela montero. *NeuroImage* 209:116496. doi: 10.1016/j.neuroimage.2019.116496

Bashwiner, D., and Bacon, D. (2019). Musical creativity and the motor system. *Curr. Opin. Behav. Sci.* 27, 146–153. doi: 10.1016/j.cobeha.2018.12.005

Beaty, R. E. (2015). The neuroscience of musical improvisation. *Neurosci. Biobeh. Rev.* 51, 108–117. doi: 10.1016/j.neubiorev.2015.01.004

Boasen, J., Takeshita, Y., Kuriki, S., and Yokosawa, K. (2018). Spectral-spatial differentiation of brain activity during mental imagery of improvisational music performance using meg. *Front. Hum. Neurosci.* 12:156. doi: 10.3389/fnhum.2018.00156

Chirico, A., Serino, S., Cipresso, P., Gaggioli, A., and Riva, G. (2015). When music "flows". state and trait in musical performance, composition and listening: a systematic review. *Front. Psychol.* 6:906. doi: 10.3389/fpsyg.2015.00906

Church, R. M. (1984). Properties of the internal clock a. *Ann. N. Y. Acad. sci.* 423, 566–582. doi: 10.1111/j.1749-6632.1984.tb23459.x

Cravo, A. M., Rohenkohl, G., Wyart, V., and Nobre, A. C. (2011). Endogenous modulation of low frequency oscillations by temporal expectations. *J. Neurophysiol.* 106, 2964–2972. doi: 10.1152/jn.00157.2011

Csikszentmihalyi, M. (1975). *Beyond Boredom and Anxiety: Experiencing Flow in Work and Play*. San Francisco; Washington; London: Jossey-Bass Publishers.

Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience*. New York, NY: Harper & Row.

Dempster, A., Laird, N., and Rubin, D. (1997). Maximum likelihood estimation from incomplete data via Em-Type algorithms. *J. R. Stat. Soc.* 39, 1–38.

Dietrich, A., and Kanso, R. (2010). A review of eeg, erp, and neuroimaging studies of creativity and insight. *Psychol. Bull.* 136:822. doi: 10.1037/a0019749

Dikaya, L. A., and Skirtach, I. A. (2015). Neurophysiological correlates of musical creativity: the example of improvisation. *Psychol. Russia* 8, 84–97. doi: 10.11621/pir.2015.0307

Dolan, D., Jensen, H. J., Mediano, P. A., Molina-Solana, M., Rajpal, H., Rosas, F., et al. (2018). The improvisational state of mind: a multidisciplinary study of an improvisatory approach to classical music repertoire performance. *Front. Psychol.* 9:1341. doi: 10.3389/fpsyg.2018.01341

Dolan, D., Sloboda, J., Jensen, H. J., Crüts, B., and Feygelson, E. (2013). The improvisatory approach to classical music performance: an empirical investigation into its characteristics and impact. *Music Perform. Res.* 6, 1–38.

Fink, A., and Benedek, M. (2014). Eeg alpha power and creative ideation. *Neurosci. Biobeh. Rev.* 44, 111–123. doi: 10.1016/j.neubiorev.2012.12.002

Fujioka, T., Ross, B., and Trainor, L. J. (2015). Beta-band oscillations represent auditory beat and its metrical hierarchy in perception and imagery. *J. Neurosci.* 35, 15187–15198. doi: 10.1523/JNEUROSCI.2397-15.2015

Fujioka, T., Trainor, L. J., Large, E. W., and Ross, B. (2012). Internalized timing of isochronous sounds is represented in neuromagnetic beta oscillations. *J. Neurosci.* 32, 1791–1802. doi: 10.1523/JNEUROSCI.4107-11.2012

Gramfort, A., Luessi, M., Larson, E., Engemann, D., Strohmeier, D., Brodbeck, C., et al. (2013). Meg and eeg data analysis with mne-python. *Front. Neurosci.* 7:267. doi: 10.3389/fnins.2013.00267

Hennequin, R., Khlif, A., Voituret, F., and Moussallam, M. (2020). Spleeter: a fast and efficient music source separation tool with pre-trained models. *J. Open Source Softw.* 5:2154. doi: 10.21105/joss.02154

Hyvarinen, A. (1999). Fast and robust fixed-point algorithms for independent component analysis. *IEEE Trans. Neural Netw.* 10, 626–634. doi: 10.1109/72.761722

Im, S.-H., and Varma, S. (2018). Distorted time perception during flow as revealed by an attention-demanding cognitive task. *Creat. Res. J.* 30, 295–304. doi: 10.1080/10400419.2018.1488346

Jicol, C., Proulx, M. J., Pollick, F. E., and Petrini, K. (2018). Long-term music training modulates the recalibration of audiovisual simultaneity. *Exp. Brain Res.* 236, 1869–1880. doi: 10.1007/s00221-018-5269-4

Kambe, J., Kakimoto, Y., and Araki, O. (2015). Phase reset affects auditory-visual simultaneity judgment. *Cogn. Neurodyn.* 9, 487–493. doi: 10.1007/s11571-015-9342-4

Landau, A. T., and Limb, C. J. (2017). The neuroscience of improvisation. *Music Educ. J.* 103, 27–33. doi: 10.1177/0027432116687373

Lerner, Y., Honey, C. J., Silbert, L. J., and Hasson, U. (2011). Topographic mapping of a hierarchy of temporal receptive windows using a narrated story. *J. Neurosci.* 31, 2906–2915. doi: 10.1523/JNEUROSCI.3684-10.2011

Lopata, J. A., Nowicki, E. A., and Joanisse, M. F. (2017). Creativity as a distinct trainable mental state: an eeg study of musical improvisation. *Neuropsychologia* 99, 246–258. doi: 10.1016/j.neuropsychologia.2017.03.020

Luft, C. D. B., Zioga, I., Thompson, N. M., Banissy, M. J., and Bhattacharya, J. (2018). Right temporal alpha oscillations as a neural mechanism for inhibiting obvious associations. *Proc. Natl. Acad. Sci. U.S.A.* 115, E12144–E12152. doi: 10.1073/pnas.1811465115

Macar, F., and Vidal, F. (2004). Event-related potentials as indices of time processing: a review. *J. Psychophysiol.* 18, 89–104. doi: 10.1027/0269-8803.18.23.89

McPherson, M., and Limb, C. J. (2013). Difficulties in the neuroscience of creativity: jazz improvisation and the scientific method. *Ann. N. Y. Acad. Sci.* 1303, 80–83. doi: 10.1111/nyas.12174

Miniussi, C., Wilding, E. L., Coull, J., and Nobre, A. C. (1999). Orienting attention in time: modulation of brain potentials. *Brain* 122, 1507–1518. doi: 10.1093/brain/122.8.1507

Mueller, M., Pardo, B. A., Mysore, G. J., and Valimaki, V. (2018). Recent advances in music signal processing [from the guest editors]. *IEEE Signal Proc. Mag.* 36, 17–19. doi: 10.1109/MSP.2018.2876190

Müller, V., Sänger, J., and Lindenberger, U. (2013). Intra-and inter-brain synchronization during musical improvisation on the guitar. *PLoS ONE* 8:e73852. doi: 10.1371/journal.pone.0073852

Nobre, A. C., and Van Ede, F. (2018). Anticipated moments: temporal structure in attention. *Nat. Rev. Neurosci.* 19:34. doi: 10.1038/nrn.2017.141

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., and Griffiths, M. D. (2019). The potential interaction between time perception and gaming: A narrative review. *Int. J. Mental Health Addict.* 18, 1226–1246. doi: 10.1007/s11469-019-00121-1

Oostenveld, R., Fries, P., Maris, E., and Schoffelen, J.-M. (2011). Fieldtrip: open source software for advanced analysis of meg, eeg, and invasive electrophysiological data. *Comput. Intell. Neurosci.* 2011:156869. doi: 10.1155/2011/156869

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., et al. (2011). Scikit-learn: machine learning in Python. *J. Mach. Learn. Res.* 12, 2825–2830.

Pinho, A. L., Ullén, F., Castelo-Branco, M., Fransson, P., and de Manzano, Ö. (2015). Addressing a paradox: dual strategies for creative performance in introspective and extrospective networks. *Cereb. Cortex* 26, 3052–3063. doi: 10.1093/cercor/bhv130

Pras, A., Schober, M. F., and Spiro, N. (2017). What about their performance do free jazz improvisers agree upon? a case study. *Front. Psychol.* 8:966. doi: 10.3389/fpsyg.2017.00966

Pressing, J. (1988). "Improvisation: methods and models," in *Generative Processes in Music*, ed J. A. Sloboda (Clarendon), 129–178.

Pressing, J. (1998) "Psychological constraints on improvisational expertise and communication," in *In the Course of Performance: Studies in the World of Musical Improvisation*, eds B. Nettl and M. Russell (Chicago, IL: University of Chicago Press), 47–67.

Rabiner, L. R. (1989). A tutorial on hidden markov models and selected applications in speech recognition. *Proc. IEEE* 77, 257–286. doi: 10.1109/5.18626

Raichle, M. E. (2015). The brain's default mode network. *Ann. Rev. Neurosci.* 38, 433–447. doi: 10.1146/annurev-neuro-071013-014030

Sanyal, S., Banerjee, A., Mukherjee, S., Guhathakurata, T., Sengupta, R., and Ghosh, D. (2016). Musical improvisation and brain correlates: an eeg based neurocognitive study using hindustani music. *J. Biomusic. Eng.* 4, 10–4172. doi: 10.4172/2090-2719.1000119

Sasaki, M., Iversen, J., and Callan, D. E. (2019). Music improvisation is characterized by increase eeg spectral power in prefrontal and perceptual motor cortical sources and can be reliably classified from non-improvisatory performance. *Front. Hum. Neurosci.* 13:435. doi: 10.3389/fnhum.2019.00435

Sitaram, R., Ros, T., Stoeckel, L., Haller, S., Scharnowski, F., Lewis-Peacock, J., et al. (2017). Closed-loop brain training: The science of neurofeedback. *Nat. Rev. Neurosci.* 18, 86–100. doi: 10.1038/nrn.2016.164

Stevens Jr, C. E., and Zabelina, D. L. (2019). Creativity comes in waves: an eeg-focused exploration of the creative brain. *Curr. Opin. Behav. Sci.* 27, 154–162. doi: 10.1016/j.cobeha.2019.02.003

Stone, J., Hunkin, N., Porrill, J., Wood, R., Keeler, V., Beanland, M., et al. (2001). When is now? perception of simultaneity. *Proc. R. Soc. Lon Ser B Biol. Sci.* 268, 31–38. doi: 10.1098/rspb.2000.1326

Stöter, F.-R., Liutkus, A., and Ito, N. (2018). "The 2018 signal separation evaluation campaign," in *International Conference on Latent Variable Analysis and Signal Separation* (Guildford: Springer), 293–305.

Tan, L., and Sin, H. X. (2019). Flow research in music contexts: a systematic literature review. *Musicae Scientiae*. doi: 10.1177/1029864919877564

Van der Schyff, D., Schiavio, A., Walton, A., Velardo, V., and Chemero, A. (2018). Musical creativity and the embodied mind: Exploring the possibilities of 4e cognition and dynamical systems theory. *Music Sci.* 1:2059204318792319. doi: 10.1177/2059204318792319

Wan, X., Crüts, B., and Jensen, H. J. (2014). The causal inference of cortical neural networks during music improvisations. *PLoS ONE* 9:e112776. doi: 10.1371/journal.pone.0112776

Wiener, M., and Kanai, R. (2016). Frequency tuning for temporal perception and prediction. *Curr. Opin. Behav. Sci.* 8, 1–6. doi: 10.1016/j.cobeha.2016.01.001

Wiener, M., Parikh, A., Krakow, A., and Coslett, H. B. (2018). An intrinsic role of beta oscillations in memory for time estimation. *Sci. Rep.* 8, 1–17. doi: 10.1038/s41598-018-26385-6

Wilson, G. B., and MacDonald, R. A. (2016). Musical choices during group free improvisation: a qualitative psychological investigation. *Psychol. Music* 44, 1029–1043. doi: 10.1177/0305735615606527

Wopereis, I., and Braam, M. (2017). "Seeking serendipity: the art of finding the unsought in professional music," in *European Conference on Information Literacy* (Saint-Malo: Springer), 503–512.

Wopereis, I., and Derix, E. (2016). "Seeking creativity: a case study on information problem solving in professional music," in *European Conference on Information Literacy* (Prague: Springer), 428–436.

Wopereis, I. G., Stoyanov, S., Kirschner, P. A., and Van Merriënboer, J. J. (2013). What makes a good musical improviser? an expert view on improvisational expertise. *Psychomusicology* 23:222. doi: 10.1037/pmu0000021

Wykowska, A., and Arstila, V. (2014). "On the flexibility of human temporal resolution," in *Subjective Time: The Philosophy, Psychology, and Neuroscience of Temporality*, eds V. Arstila and D. Lloyd (Cambridge, MA: MIT Press), 431–451.

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Taqsīm as a Creative Musical Process in Arabic Music

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Creativity plays a major role in various musical contexts including composition, performance and education. Although numerous studies have revealed how creativity is involved in processes of listening, improvising and composing, relatively little is known about the particularities of transcultural creative processes in music. In this article, we aim to shed light on the creative musical processes underlying taqsīm performance in Arabic music. To that end, qualitative interviews have been conducted with three Berlin-based oud players from Syria. Results of a thematic content analysis show that taqsīm encompasses multiple components (e.g., a flexible form and dependency on maqam as well as tonal music) and serves various functions such as developing artistic individuality. Moreover, taqsīm is affected by interactions between tradition and novelty. We discuss the interview data within the cross-cultural experiential model of musical creativity developed by Hill (2018), offering a fresh approach to studying taqsīm which goes beyond established concepts such as the improvisation-composition continuum.

Keywords: taqsīm, Arabic music, musical creativity, composition, improvisation

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INTRODUCTION

The relationship between music and creativity has been studied from numerous angles, including creativity and listening (Peterson, 2006), creativity in educational settings (Crow, 2008; Odena and Welch, 2012), and creativity and musical performance (Deliège and Wiggins, 2006). Schiavio and Benedek (2020) have recently argued that previously posed theories of creativity in musical and non-musical domains distinguished between the following four types of creativity: (1) individual creativity, which focuses on comparing the creative products of individual subjects and linking them to individual differences (Auh, 1997; Villarreal et al., 2013); (2) collective creativity (Clarke and Doffman(eds), 2017; Bishop, 2018), which is focused on distributed activity across members of music ensembles as well as on composer-performer creative collaboration. This approach stresses the social aspect of music-making. Researchers like Burnard (2012a) have argued that a singular understanding of musical creativity (like the one achieved by individual composers) resulted in a limited definition of creativity. Alternatively, a collectivist perspective on music can be a source of meaningful socio-historical representations of objects and actions. From such a viewpoint, the audience (as a community) plays a crucial role in influencing and co-creating creativity. Further, concepts of creativity can be rooted within socio-cultural contexts, where creativity practices can be conceptualized as being situated and collective (Kenny, 2014). The social and cultural contexts in which creativity in music occurs allow researchers to investigate a wide scope of musical genres like improvised music (Burnard, 2012a). Psychologists and cognitive scientists are interested in (3) domain-general perspectives on creativity (Beaty et al., 2013), arguing that domain-general abilities influence and may predict domain-specific abilities. A contrary approach is to focus on (4) domain-specific perspectives on creativity (Baer, 2015). In such studies, it is argued that creativity in one domain does not predict creativity in other unrelated domains. Schiavio and Benedek (2020) highlight that these aspects should not be understood as alternatives. To reduce the tension between these poles, they draw from a range of scholarship in music and enactive cognitive science, and suggest that creative cognition may be best understood as a process of skillful organism-environment adaptation that can be cultivated continually. Moreover, other researchers explored connections and tensions between creativity research and developmental psychology (Sawyer et al., 2003). In addition to that, musical creativity can be studied with the paradigm of embodied cognition (Nagy, 2016; Van der Schyff et al., 2018).

With regard to musical activities, Hargreaves et al. (2011) have argued that there are common mental structures underlying the three main activities of music: invention (composing and improvising), performance of music, and listening to it, and that these structures reveal imagination and creativity (see also Hargreaves, 2012). The activities of music invention (i.e., composing and improvising) are often presented in the literature as endpoints of a continuum (Pressing, 1984; Sarath, 1996; Lehmann, 2005; Goldman, 2019), although a strict separation can be doubted from a psychological perspective (Lehmann and Kopiez, 2010). It is also questionable whether cultural constructs such as "composition" and "improvisation" can be adapted to examine the wide range of *transcultural* creative processes in different musics. We use the term transcultural to denote that (musical-) cultures may have boundaries, yet these boundaries are not absolute or even clearly defined. Thus, a transcultural perspective indicates "a procedural act of a cultural overstepping of boundaries or the condition which results from this overstepping of boundaries" (Kim, 2017, p. 20). Moreover, creative thinking in music is not restricted to one genre, style or historical era, rather it is a general feature found in many musical activities (Campbell, 1990). Studying musical creativity would therefore benefit from including a wider range of musical practices and their components.

Besides studying music practices from a transcultural point of view, the mobility of musical genres and practices as well as studying migrants' music may reveal new interconnections between creative musical processes. Baily and Collyer (2006) point out that the cultural and spatial distance between the cultural background of the migrants and the culture of the settlement place affect the musical practice in the migration situation. Sorce Keller and Barwick (2012) note that studying musical attitudes, tastes, and practices can provide valuable insights into the details of processes like assimilation, co-habitation and the maintenance of distinctive cultural traits. Furthermore, Baily and Collyer (2006) state that cultural innovation and enrichment may result from migration.

Here, we propose that shedding light on taqsīm—a musical practice in Arabic, Turkish and Persian cultures—can enrich our perspective on creative processes in music and inform the wider musicological and cognitive science discourse. Taqsīm is a musical practice dependent on oral transmission, which may allow space for novelty but may make it vulnerable to significant changes in a globalized world. It also has an open and more flexible form compared to other Arabic compositional forms or European forms of classical music. The term taqsīm (plural: taqāsīm) refers to a non-metric improvised solo form in Arabic music. The word itself means "division," implying variation and improvisation (Nettl, 1974). Marcus (1993) points out that taqāsīm are not simply free-formed products of the musician's fantasy. He notes that the player improvises according to a complex set of pre-established rules and conventions. Taqsīm, according to Marcus (1993), is a highly valued musical genre in Arabic music because it gives the players the opportunity to present their own creations instead of relying on the compositions of others. Racy (2000) elaborates on this point by adding that the ability to play taqsīm is generally considered a characteristic of good musicianship in the Arab world. Racy also notes that playing taqsīm, which may be heard in combination with non-improvised compositions or alone, is known to require extraordinary skill, talent, and inspiration. Watson (2012) notes that taqsīm can be performed unaccompanied or accompanied. In accompanied settings, taqsīm is often played over a single-pitch drone without rhythmic accompaniment. Alternatively, taqsīm can also occur over a repeated ostinato, or within a repeated percussion cycle.

Composition and Improvisation

Taqsīm is often seen as an improvisatory genre (Touma, 1971; Nettl and Riddle, 1973; Racy, 2000; Shannon, 2003; Watson, 2012). Yet, a strict separation between composition and improvisation can be doubted. Nettl (1974) highlights that improvisation has been considered as a type of composition that characterizes musical cultures without notation. This type of composition depends on releasing sudden impulses to music through direct production of sound. According to Nettl, it has been argued that improvisation ends where notation begins, while others contend that certain non-western cultures, which do not use notation, distinguish between the two processes by internally classifying their musics. Taqsīm is rarely notated—maybe only for theoretical analysis by musicologists—yet, as Nettl notes, the absence of notation is not enough to describe some musical genres as improvisation. Improvisation and composition can be seen as creative music-making processes (Lehmann and Kopiez, 2002). Moreover, Nettl (1974) proposed a continuum-based definition where composition and improvisation are thought of as being at the "opposite ends of a continuum." However, it is not clear whether it is sensible to locate taqsīm on such a linear binary continuum, because we would still need to define improvisation and composition to establish such a continuum. Despite Nettl's suggestion to consider composition and improvisation as being at the opposite ends of a continuum, the wider observation of many musical traditions around the world led him to conclude that "perhaps we must abandon the idea of improvisation as a process separate from composition and adopt the view that all performers improvise to some extent" (Nettl, 1974, p. 19). He later expresses further doubt, stating that "we probably should never have started calling it improvisation" (Solis and Nettl, 2009, ix). Similarly, Nooshin (2017) suggests that the continuum model did not go far enough. Nooshin argues that a better understanding of creative processes would ultimately require a complete dissolution of the composition/improvisation dichotomy. Moreover, Lehmann and Kopiez (2002) point out that composition and improvisation are much more akin than commonly assumed. By analyzing optimization processes and constraints on the creative performer and process, Lehmann and Kopiez show that both processes tap into the same mental mechanisms and require similar prerequisites. They conclude that such a view opens up new ways of investigating generative creativity in music.

However, some researchers may argue that there are important differences between composition and improvisation. Sloboda (1986) argues that what distinguishes improvisation from composition is the pre-existence of a large set of formal constraints which comprise a "blueprint" or "skeleton" for the improvisation. Sloboda notes that the improviser, who depends on a "blueprint," can manage without much of the composer's usual decision-making process especially in aspects like structure and direction. Sloboda argues that while the composer may keep rejecting possible solutions during composing until finding a more suitable one, the improviser has to do with the first solution that comes to mind. Moreover, temporality is another aspect which may distinguish composition and improvisation. Sarath (1996) argues that while the improviser experiences time in an "inner-directed" manner, where the present is so central in comparison to the past and future, the composer has an "expanding" temporality, which means that the "temporal projections may be conceived from any moment in a work to past and future time coordinates" (Sarath, 1996, p. 1).

Moreover, Mazzola et al. (2011) give a detailed characterization of the creativity processes in composition and improvisation. The creativity process in composition can be characterized as: (1) reliance on symbolic musical objects as elements of a semiotic context which unfolds in a logical time (the rules that govern the shape and arrangement of material in the parameter space of the symbolic events); (2) reliance on basic semiotic architecture which manipulates symbols in a referential network that operates in independence of material time; and (3) a separation of material components from the transformation rules. The creativity process in improvisation can be characterized as: (1) reliance on a system of gesture that does not allow for abstract symbols; (2) reliance on managing of gestures through the connectivity of gestures within hypergestures; and (3) no separation of components from the transformation rules.

However, Mazzola et al. (2011) add that both composition and improvisation can be seen from their generative aspect, thus one can say that "improvisation is instant composition while composition is slow-motion improvisation" (2011, p. 245). In this sense "[t]he generative forces of the compositional logic are not necessarily logical, but they may very well be nourished by gestures of memory, dreams, and yearnings." (2011, p. 246). Moreover, "[t]he imaginary space-time of improvisation is in itself a kernel structure for a compositional approach to improvisation since it creates a space for musical construction as if we were working out a compositional preconception." (2011, p. 247).

Rose et al. (2012) also challenged the differentiation of improvisation and composition by conceptualizing improvisation as an instant composition. They add that "[r]eal-time composition becomes realized by means of the body and embodied knowledge and the body can be thought of as the site of improvisation." (2012, p. 210).

As the literature discussed so far suggests, it is not adequate to assume that taqsīm is simply an improvisatory genre. Instead, it could be more revealing to examine taqsīm as a broader creative music-making process. Glăveanu (2019) proposes three different types of logic that can be used to study creativity culturally: (1) the logic of comparison, which focuses on comparability of creativity-related phenomena and is used in most cross-cultural research; (2) the logic of exploration, which highlights differences in creativity between individuals and groups, mostly used in cultural or sociocultural research; and (3) the logic of understanding, which is used in the research depending on local and bottom-up definitions and categories.

Burnard (2012a) provides a rich framework to study musical creativity. She argues that musical creativities can take many forms, may have many functions, and are contained in personal and sociocultural contexts. She distinguishes between forms of authorship, mediating modalities and practice principles of different musical practices. Moreover, according to her, these elements mediate between individual, social and cultural systems. Yet, she distinguishes between composed music and improvised music – a distinction which can be doubted, as argued above.

Hill's Experiential[1] Model of Musical Creativity

Another framework in which the underlying processes of taqsīm may be discussed more fruitfully is provided by Hill (2018). According to Hill, creativity can be seen as a fundamental human desire and activity that is culturally embedded and socially regulated. She conducted in-depth qualitative research with more than one hundred musicians from different communities. Her research dealing with examples from classical, jazz, and traditional musicians in three cities—Cape Town, Helsinki, and Los Angeles—explored musicians' thoughts on, and experiences of, the development and practice of musical creativity.

While Hill values the view of the diversity of creative activities and of musical cultures in which they occur as articulated by Burnard's (2012b), Hill aims to "identify the most common components of creative experience" (Hill, 2018, p. 3). Based on her comparative research in these diverse cultural contexts, she proposes a model of creativity that contains components of generativity, agency, interaction, non-conformity, recycling, and flow. She notes that all these six components were reported across all the musical idioms and cultures in her study (Hill, 2018).

[1] Hill uses the term experiential to emphasize the musicians' experience which distinguishes her research from the common creativity literature, which focuses on external evaluation of creative products, J. Hill (personal communication, March 15, 2021).

Hill (2018) notes that some cultures may place greater value on some of these components than on others. She notes that the restriction of any one of these components may result in an inhibition of creativity. On the other hand, she argues, supporting all six components can enhance creative potential. Hill (2018) notes that more research is needed to test whether her model is applicable across a broader range of musical cultures.

By exploring three musicians' reflections on their experience of taqsīm, this study aims to examine whether taqsīm and the musical processes underpinning taqsīm performance in Arabic music may be described within Hill's model of cross-cultural musical creativity.

MATERIALS AND METHODS

Participants

Participants were three male oud players from Syria: Ala'a, Wassim and Nabil – aged 28, 34, and 37, respectively – who have lived in Berlin since 2015/16. The participants had had private music lessons since childhood and preadolescence. Wassim and Nabil started taking oud lessons when they were 10 years old, while Ala'a began at the age of 13 years. All three are familiar with solfège and musical notation. They used to give public concerts in Syria and expanded their musical activities in Berlin through workshops, solo performances, and participation in ensembles of various sizes. Each participant signed a consent form, and the study was carried out in accordance with the Declaration of Helsinki.

Materials and Procedure

Half-open questions were used to interview all three musicians. The aim was to explore the musicians' reflections on their experience of taqsīm. We asked the musicians about the definition, form, function, learning of taqsīm, and also about playing taqsīm in different situations (solo vs. ensemble, with vs. without an audience), as well as about the development of their own taqsīm in the last few years. To what extent is taqsīm free or limited, and how does it compare to composition or improvisation in general? The interviews were conducted in Arabic – the mother tongue of the three participants and the first author – in January and February 2019. The interview with Ala'a took place at the interviewer's home, Nabil's at his home, and Wassim's in the Department of Musicology and Media Studies at Humboldt-Universität zu Berlin. Each interview lasted roughly 35 min. The interview was recorded with a Zoom H5 Audio Recorder and later transcribed into Arabic and then translated into English.

Data Analysis

A thematic content analysis with the deductive (or top-down) approach was used to analyze the interviews (Hayes, 1997; Boyatzis, 1998; Braun and Clarke, 2006). Reading the original transcription and the translation of the interviews multiple times was the first step in the analysis to get familiar with the data. The translations were checked back with the original recordings to assure accuracy. The literature review on taqsīm gave rise to preliminary codes that were assigned to the data to describe the content. The literature review helped us to code the participant answers by providing us with keywords and central concepts to look for. Examples of such keywords and concepts were: musical environment, maqam music, taqsīm in concerts, interaction with the audience and other musicians, musical material, building blocks, development of taqsīm. Data reduction and inferences about the codes' meaning were made, and we examined how the themes support the overarching theoretical perspective. Each interview was analyzed separately, later the themes and codes across the three interviews were compared. This enabled us to find similarities and differences in our participants' answers. Afterward, themes were reviewed and precisely named. A final list of codes and three main themes was produced. These final codes were mapped to the components of Hill's model. We further discuss the extent to which Hill's components of creative experience can be found in taqsīm.

FINDINGS

After conducting the thematic content analysis, the following final codes emerged, which we grouped into the following themes: Interaction – Creation – Freedom/limitation.

Summary of the final codes:

- Instant composition
- Flexible form
- Highlighting the technical skills of the player
- As an introduction for a piece
- A space for interaction
- Learning by imitation
- Creating one's own taqsīm
- Recycled musical material
- Audience effect on taqsīm
- Playing with an ensemble affects taqsīm
- A meditative state
- Integrating elements from different styles
- Microtonal intervals and other instruments
- Leaving Syria/being in Berlin

A flexible form as the main feature of taqsīm was evident in taqsīm definitions given by all three participants. For Ala'a, besides being "a genre or musical form in oriental music in general and in Arabic music in particular" taqsīm is "a free form that is based on the character of the musician, his repertoire, his cultural heritage of musical phrases, or learned techniques." Ala'a noted that taqsīm consists of four parts: an introduction, the body of the taqsīm, a kind of development, and a conclusion. Wassim gave a general description of his taqsīm form and stated:

> "I build melodies on rhythmic patterns and follow the rules of tetrachords and their order so that I can build musical phrases and develop them and then move on to new musical phrases. Later I set a conclusion, which is a kind of summary of the previous phrases."

Nabil stated that he would not use a form to structure his taqsīm and added: "taqsīm should be as free as possible." The answers of the participants highlight that maqam is central to taqsīm. For Ala'a, taqsīm aims to present the maqam of the taqsīm. For Wassim, the taqsīm follows the logic of the maqam. Nabil noted that "the taqsīm introduces the maqam [which will be] sung by the singer."

There were mixed answers concerning the freedom of taqsīm. The participants pointed out that taqsīm is free but may be limited by other factors such as the setting (many musicians playing together makes it hard to coordinate who will play next and for how long) and time factors (many musicians playing taqsīm may result in a very long performance). However, Wassim noted that taqsīm may be stylistically restricted: "taqsīm follows the tonal rules." Ala'a and Nabil noted that playing with other bands (especially orchestras or bands that play music with harmonic progression) may limit their taqsīm freedom. These answers support the idea that taqsīm has rules and is not completely free.

When asked about how they learned taqsīm, the participants highlighted multiple learning processes: Ala'a learned taqsīm through listening and being more experienced with Arabic musical tradition. Nabil stated that he always tended to vary the music he learned to play; later, he started to imitate oud masters' taqsīm. While Ala'a's and Nabil's learning processes of taqsīm can be described as autodidactic, Wassim stated that taqsīm was organized by his teachers, with the goal of playing musical elements on the oud.

The three participants accumulate experiences and use their repertoire on the spot of performance. Nabil stated that after playing in many concerts, he has developed many musical ideas he can use in his taqsīm. Besides these experiences in concerts, he develops taqsīm when he is at home practicing. Wassim pointed out two sources for his experience with taqsīm: (1) the interaction with his teachers and (2) experimenting with his instruments. Ala'a depends on his repertoire, which has been built up and collected over several years. The participants highlighted that the musical material played during taqsīm comes from songs, the traditional musical repertoire and the individual experimentation with the instrument and the maqams. These processes indicate that the players internalized stylistic rules that characterize taqsīm by making themselves more familiar with the material through listening and imitating. Yet these rules were not absolute: All players reported influences on their taqsīm music from other musical cultures: For Ala'a, Turkish music, blues and jazz. For Nabil, electronic music and European classical music. For Wassim, music from Azerbaijan and European classical music.

Concerning the role of the audience, the participants' answers revealed that the interaction with the audience and concert settings have a great influence on taqsīm. Wassim noted that taqsīm functions as an interaction space with the audience, the music itself, and with other players. Yet having an audience may put the player under pressure according to Nabil. Ala'a noted that when he plays in front of an audience there is more enthusiasm. He added that there is a competition between the players to impress the audience.

Moving to Berlin from Syria was seen by our participants as an opportunity to develop their own taqsīm. Ala'a stated:

> "The audience I had in Syria was very different from the audience I have in Germany and in Europe in general. I can say that I didn't really have an audience in Syria because I was giving concerts in small places and people in general were not fans of this style and I always used to cut something from the taqsīm."

Nabil stated:

> "I don't play taqsīm in Germany the way I play it in Syria. The difference is very big, because here I started to hear jazz improvisations, rock music and live electronic music in a very different way than I heard them in Syria. In Syria, I heard them as recordings and these recordings are pieces of music for me because they are recorded. When I went to hear them again, the music was the same. But when I heard and met the musicians who improvise this music, I started to hear this music differently. Even when the same player improvises again, he repeats the improvisation differently. I started to see them as improvisations and adopting many ideas from them. I have the impression that the ear of the audience [in Europe] is different, so my music changes according to the expectations of the listener. My music has been influenced in this way a lot, not only my improvisation, [but] my compositions also. They got influenced by the music I hear here and by the audience I play for."

Wassim stated:

> "I can say that almost five years after leaving Syria, I have the possibility to really check what I have. Besides the freedom of dealing with a completely new audience, whether a Turkish audience or a European audience. These gave me some freedom. That is, I don't have to do anything. Everything I do, I want to do and not because I have to do it."

The answers of our participants indicate that room for individual artistic expression is a primary function of taqsīm. This was evident in the taqsīm definition given by Ala'a: "a free form that is based on the character of the musician, his repertoire, his cultural heritage of musical phrases, or learned techniques." For Nabil, taqsīm functions as a space in which the player presents his instrument, technique, and musical abilities. For Wassim, taqsīm functions as a space to show the technical skills of the player.

DISCUSSION

The participants' answers show that taqsīm has several special characteristics: a musical genre with a flexible form; the importance of maqam to taqsīm; performing taqsīm is governed by rules and not completely free, although such rules are not always explicit and clear to the players themselves; the existence of such rules does not prevent the players from being open to new musical materials; interaction with the audience plays an important role while performing taqsīm; artistic self-expression is central to taqsīm. Seeing taqsīm as an improvisatory genre is not a satisfactory approach, as discussed in the introduction. Thus, we seek to interpret our data within an alternative approach. We will examine whether our data on taqsīm fit within Hill's model of creativity, paying attention to each component and whether we can find counterparts of these components in our participants' answers.

Generativity

According to Hill (2018), generativity is the most basic aspect of the creative process. Hill notes that this aspect can be described as "building," "making," "creating," or "constructing" something. Hill adds that musicians and music scholars mostly agree that composing, improvising, and arranging music are creative generative acts. However, she notes that there is less agreement on whether performing a pre-existing work should be considered creative. A similar position was expressed by Nettl (1974) who suggested that it is self-evident that improvised music requires a greater creative effort on the part of the performer than does composed music. Nettl noted that improvisation may be defined by measuring the degree to which the performer is creatively involved.

In this study, when the participants talked about taqsīm they used expressions denoting the generative nature of the process. Ala'a used verbs like "create" and "build" to talk about taqsīm. Ala'a noted that taqsīm is a creation that uses building blocks from the player's repertoire. For him these building blocks are:

> "the player's repertoire that he builds and collects over several years. If you are a player in the first level, that is, in your first or second year, you can create a taqsīm, but it can [only] be [either] traditional or a mixture of the songs of Fairuz and Umm Kulthum that you play in your first phase."

This repertoire and cultural heritage of the musician (like maqams) and the musician's technical skills play an important role in building taqsīm:

> "It is a kind of free form that depends on the musician's character, his repertoire, his cultural heritage of musical phrases, or learned techniques. It is related to his ability to implement his repertoire in a form determined by rules—to present his feelings through the use of the repertoire he possesses or the technique he has learned, and to present the maqam on which the musician builds his taqsīm, to the listener."

Nabil also used the verbs "create" and "build" to talk about his taqsīm, with a focus on the idea that with time he started to create his own building blocks, instead of borrowing from other musicians:

> "With time and with repetition, I was moving away from the basic musical ideas and the main melodies of the [original] musicians. I started to create a line [melody] that I liked and I [started to] focus on the ideas that I want and like. Like that and with time I became able to create a taqsīm that convinced me."

Wassim used the verb "build" with melodies and musical phrases. For Wassim, the process is comparable to composition, especially when he speaks about building and developing musical phrases which leads to growth:

> "taqsīm from the point of view of classical oriental music [...] is tonal music accomplished through building melodies on a rhythmic pattern and they follow the rules of tetrachords. Building phrases and developing them and then move on to new phrases. And later adding a conclusion, which is a kind of summary of the previous phrases."

Indeed, the connection to composition becomes clear in the following quote from Wassim, even though it is a kind of instant composition:

> "What is special about taqsīm is that it is a work that is composed immediately [while playing]."

This generativity is goal-oriented, as mentioned above. Such goals can be summarized as: (1) room for individual artistic expression, (2) interaction with the audience, and (3) support and introduction of pre-composed pieces.

Agency

The second component of creativity according to Hill (2018) is agency, which was also the most important component for the majority of musicians she interviewed. Agency can be seen as "individuals' 'room for action', and the extent to which we are either subdued by the larger mechanisms of society or can freely decide our ways of being and acting within them" (Karlsen, 2011, p. 110). Such an understanding of agency emphasizes the ability to make one's own decisions determining musical act and meaning. According to Marcus (1993) taqsīm allows the musicians to demonstrate their abilities as composers and their mastery of their instruments.

Our participants' answers highlight the importance of agency. For Ala'a, taqsīm is a musical space which is built from "the musician's character, his repertoire, his cultural heritage of musical phrases, or learned techniques." This shows that taqsīm style is related strongly to the musician's personality and individuality. Moreover, playing taqsīm before or within a pre-composed piece of music "opens up a way for any musician to add some of his spirit to the piece and make the piece a combination of several spirits ...." In this way, the player is not only a performer of a pre-composed piece, but rather a co-creator. The player may add, invent or change the form of a piece by playing a taqsīm of his own, before or during the piece, where he has the chance to introduce his individuality as a creator.

Nabil expressed similar ideas. For him, taqsīm is "the most important opportunity for the musician to present himself. He presents himself as a musician with spirit and technique and he reflects the atmosphere of the concert." Moreover, taqsīm gives the player control over the material of the concert because it is not pre-composed. Thus, the player has the choice to adapt his taqsīm to a different concert situation accordingly.

Wassim stated that taqsīm "should emphasize the player's technical skills, the understanding of his instrument and interaction with the audience, with the music itself, and with the other players." Besides showing their technical skills, taqsīm allows the players to interact as active agents.

Interaction

Hill (2018) points out that the next component of her cross-cultural model of musical creativity can be shadowed – especially in western culture – by agency, namely the interaction component. According to Hill (2018, p. 5) "(i)nteraction includes being stimulated by and responding to input from musicians, audience members, and the environment." Interaction, according to Hill, includes being engaged with the other musicians with whom one plays and with the audience. During taqsīm performance, the same musicians may perform in varied styles, depending largely upon their emotional state during the performance and upon the nature of their audience (Racy, 1991).

Our participants expressed that interaction is an important aspect of taqsīm. For Ala'a, taqsīm "will change because there are other people [an audience]." Moreover, having other players with whom one plays changes taqsīm as well because there is "competition with the other players."

For Nabil, taqsīm is "a direct interaction between the player and the audience." To Nabil, such interaction is multidimensional "[with] the audience on one hand and [with] the band [with whom one plays] on the other hand."

For Wassim, taqsīm is "meant to highlight the technical skills of the player, his understanding of his instrument and interaction with the audience and with the music itself and also with other players."

In addition to the interaction with the audience and with other musicians through taqsīm, as expressed by Ala'a and Nabil, Wassim added that taqsīm is in interaction with the (pre-composed) music itself, especially when taqsīm is played before or within a piece:

> "In my opinion, the taqsīm has essentially two roles: the first role is to introduce the pieces by bringing the musicians and the audience into a state where there is a preparation for the atmosphere of the piece. Later to get into the piece, so that the piece does not come as a surprise [. . .]. This is the first role. The second role is to have one or more solos for one or more instruments within the piece before the conclusion [...]."

The participants' answers point out that interaction while performing taqsīm might manifest itself in various ways and on various levels. There is interaction with the audience, other musicians, and with the music itself.

Non-conformity

To encompass a cluster of concepts such as novelty, innovation, difference, and originality, Hill (2018) uses the term non-conformity, as the fourth component of her model of musical creativity. Hill argues that this term helps to (a) explain why and how creativity is restricted by social pressures to conform to norms and standards and (b) to note that innovation and novelty may not always be valued within music cultures that prioritize historical authenticity and preservation of tradition. However, Hill points out that this does not mean that such traditionally oriented music cultures do not allow for creativity. On the contrary, according to her, an extensive expression of creativity can exist within the bounds of tradition. Hill notes that the creative musician explores and realizes multiple possibilities instead of conforming to an entirely predetermined model. According to Ayari and McAdams (2003), taqsīm is organized into several phases in the presentation and development of each maqam. However, they note that the precise ordering is not fixed: introduction, presentation of the basic maqam elements, exposition, re-exposition, and confirmation. Ayari and McAdams add that some performers may linger on a given phase of taqsīm before moving to the execution of another idea. They add that the duration of each phase depends on the artistic mastery of each performer. Such a flexible form may facilitate non-conformity.

Our participants expressed their attempt to integrate musical material from sources other than Arabic musical tradition. For example, Ala'a borrows "some techniques of Turkish music" and "a combination of jazz and blues, especially after coming to Europe and learning more about these styles and playing with bands that play these styles." More specifically, Ala'a noted he has "a tendency to use certain blues scales in the bridge of the maqam while keeping the shape of the maqam."

For Nabil, being in Berlin gave him the chance to encounter electronic music. "I am trying to learn the technique of repetition in electronic music." He described how he can deviate from traditional musical ideas:

> "I have moved away from the basic musical ideas and the main melodies of the [original] musicians. I created melodies that I like, and decided to concentrate on the ideas that I wanted to create to build a taqsīm that would convince me."

Wassim integrated elements of Azerbaijani music into his taqsīm style because one of his teachers was Azerbaijani. Moreover, moving to Berlin and having a new audience gave him more freedom to vary his taqsīm. This freedom comes from the fact that his audience in Berlin includes – in addition to listeners familiar with Arabic music – listeners familiar with Turkish music or European classical music. Thus he has the freedom to vary his taqsīm and he does not have to stick with only the "Arabic way" of playing taqsīm.

These insights show that the participants were seeking to integrate non-traditional elements into their own taqsīm. These elements are related to their interest in other musical genres and styles. Moreover, there is some intersection in their preferences and choices. However, the elements they choose to integrate into their taqsīm may vary considerably: they could be musical phrases (building blocks), technical skills, or esthetic principles.

Recycling

The fifth component of Hill's model of musical creativity is recycling. Hill (2018) notes that creative processes also depend on recycling, or reusing, remixing, and otherwise building on, tradition. Racy (2000) notes that a taqsīm in a specific maqam, or melodic mode, tends to be self-contained. This means that it is begun, developed, and resolved in accordance with an established modal plan. In many cases, the material that builds such a structure is borrowed. Watson (2012) points out that, even though most taqsīm performers view it as having no rules as such, there is certainly a necessity for traditional musical details to be enacted during the performance. Such details, Watson notes, are internalized by modeling musical behavior on traditional prototypes. Watson adds that the methods through which musicians develop the ability to produce genre-specific musical elements are enabled by engaging in various learning environments such as parental apprenticeships, informal apprenticeships with master musicians, vocalists and ensembles, musician networks, autodidactic study, and institutionalized study. Watson (2012) points out that musicians who play taqsīm and other genres absorb pre-composed melodic prototypes as stylistic and theoretical blueprints.

Ala'a stated that "borrowing phrases from a song or an older work is a normal thing, because this is the repertoire of the musician that gets realized and embodied."

Nabil describes listening to taqsīm masters and trying "to repeat them as if they were pieces." Moreover, Nabil's teachers told him that "the musician gets richer every time he learns pieces and taqsīms from other musicians." Nabil elaborated: "Sometimes it is possible to build a taqsīm from a song without the audience noticing. The musician can take ideas from a song and change them—or from a melody or a piece—and make a taqsīm out of it."

For Wassim, the melodies heard within taqsīm have different sources, but mainly they are based on "sequences of the tetrachords and on the repertoire of each musician."

These insights from our interviews show that it is a common practice to use recycled materials when playing taqsīm. These materials may be motives or melody segments from songs and other pieces or more abstract building blocks like maqams.

Flow

Flow is the sixth component of Hill's model of musical creativity (Hill, 2018). She points out that Csikszentmihalyi, (1996, p. 110) defines flow as "the feeling when things were going well as an almost automatic, effortless, yet highly focused state of consciousness." According to Shannon (2003), music lovers and performers of the classical Arab musical repertoire associate esthetic quality and authenticity with the ability of artists and their audiences to achieve tarab. Shannon (2003, p. 74) further notes that in Arabic, tarab refers linguistically to "a state of heightened emotionality, often translated as 'rapture,' 'ecstasy,' or 'enchantment' but can also indicate sadness as well as joy." Shannon adds that tarab also describes a style of music and musical performance which evoke such emotional states in performers and audiences. According to Shannon (2003), in the performance of a taqsīm, an artist can establish a sense of *saltana* which Shannon describes as melodic flow or groove. Shannon suggests that these strategies have the effect of altering the listener's experience of temporality. According to Shannon, the experience of detemporalization and retemporalization may in fact be critical to the production of tarab. Shannon points out that although technical ability may generate excitement among audiences, for listeners, the artists' ability to alter the experience of time is a primary indicator of their creativity and authenticity. Shannon notes that listening to a traditional taqsīm brings listeners out of the normal flow of time where melodic repetition and fluency of movement create a sense of suspended time.

In our study, the musicians expressed comparable opinions. Ala'a stated that "when the time of the taqsīm comes and I play my taqsīm, I may close my eyes because I am building inner images and experiencing a certain situation." Ala'a expressed a common experience related to flow, which is forgetting the surroundings.

Nabil feels "absolutely free in solo concerts." Moreover, he describes how he plays his music for himself: "A large part of the music is not for other people. I do what I am convinced of, what I feel." Following his feelings without a pre-established plan can be seen as an important part of the flow experiences.

When Wassim plays on his own he feels that he is free and able to "enter into a situation that is similar to a dialogue with the self and [similar to] a Sufi experience." He added that he may enter a state comparable to flow when playing on his own, where he does not feel the pressure of having an audience: "I don't have the crisis [the issue, the question] whether the audience is enjoying it or not. Therefore, I can take long breaks and enter into a situation that is closer to the dialogue with the self and a Sufi process... Meditation through the music." When asked about playing with others, Wassim stated:

> "The solo player [in such a situation] has less freedom for the taqsīm, but at the same time there is a higher level of communication, because at that moment [the whole] ensemble can participate [in playing, and this can be] a spiritual experience."

Wassim's statement may point to a sense of *saltana* which Shannon (2003) describes as melodic flow or groove. Yet these experiences need further investigation to find out whether *saltana* is part of a flow experience or not. The mapping of the interview final codes and Hill's model is shown in **Figure 1**.

Tensions

Hill (2018) points out that all these components—generativity, agency, interaction, non-conformity, recycling, and flow—usually coexist and overlap. However, tensions between them may occur. According to Hill, interaction and recycling can be hindered by too much focus on individual agency and non-conformity. Moreover, agency, non-conformity, and flow can be hindered by too much concern about external evaluation.

We found some indications of tensions in our participants' answers. These tensions might be a part of interaction in different situations. For example, Ala'a noted the audience evaluation is important during taqsīm:

> "Maybe the musician experiences an ideal state, that is, he feels that he is playing a beautiful taqsīm, but the audience is wondering what this person is doing on stage."

This statement shows that there might be a tension between agency and external evaluation of the creative process. Nabil pointed out that tensions may occur among musicians playing together. He might wish to play a free taqsīm without a pre-determined duration but this can be irritating to other musicians:

> "A long taqsīm puts pressure on the other musicians on stage, who are waiting for it to end!"

Moreover, he noted that taqsīm—when performed within a piece—should fit that piece, which may create a tension between the generated material on stage and the pre-composed piece:

> "I can think that the taqsīm is beautiful and the audience enjoys it, but it doesn't fit well with the piece."

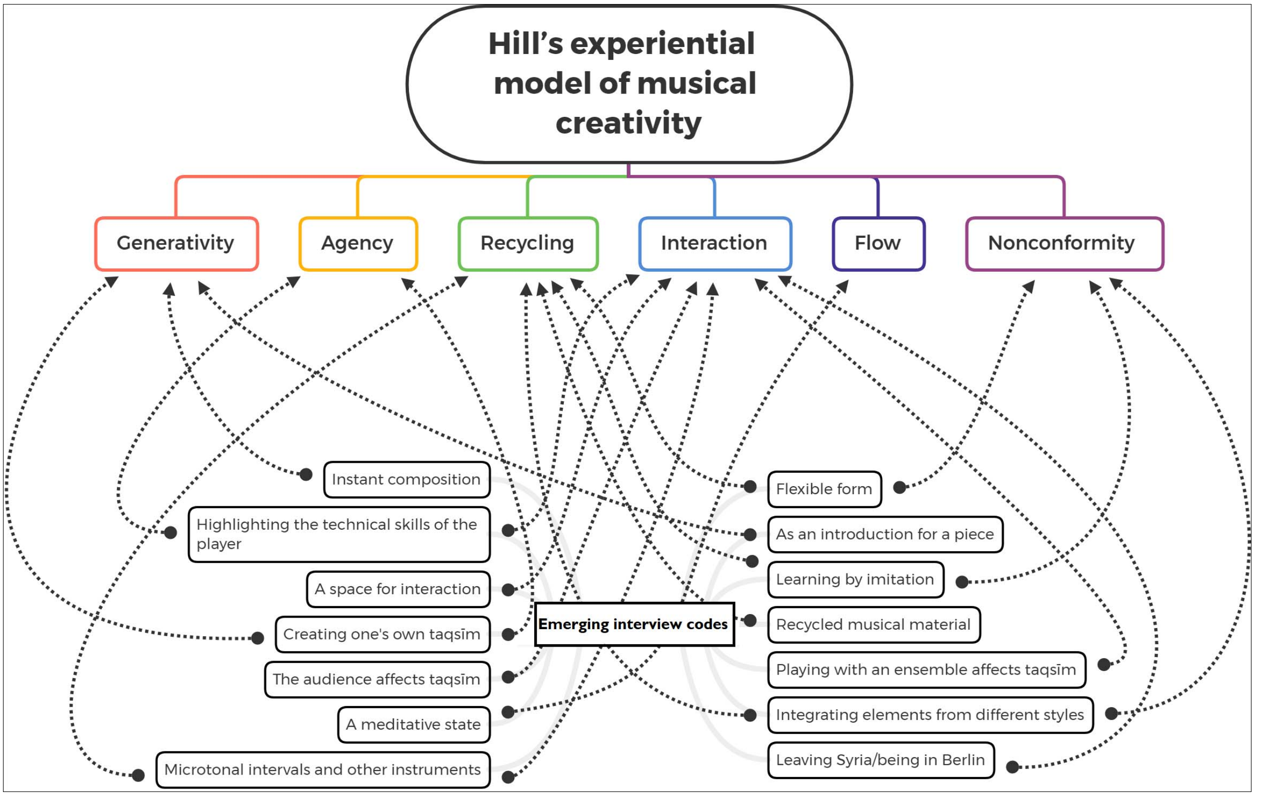

FIGURE 1 | Mapping between the interview codes and Hill's model components of musical creativity (generativity, agency, interaction, non-conformity, recycling, and flow). All components of Hill's model were evident in our analysis of the particpants' answers on taqsīm.

In addition to that, playing with an orchestra may limit the freedom of taqsīm:

> "For example, they [the orchestra, other musicians] asked me to create a clear and specific duration of taqsīm. So I had to make a taqsīm that is similar to a composition, because I had to know exactly what I was going to do and play."

These examples given by Nabil point out a pressure to adapt to other musicians, pre-composed pieces, or to other musical practices (like playing with an orchestra). A further tension may take place between the desire to be creative and the concern about feedback from the audience. Nabil stated:

> "I try to play original material in every concert, when I do so, I feel happy and comfortable and feel that the taqsīm is more than just a repetition. [. . .] When I play for an audience, there is a lack of oxygen in my body because I am nervous. Also, because I'm afraid of making mistakes. I have to say that [there] I am less brave. My [musical] thoughts at home are always more important, because even if I make a mistake, big or small, I can repeat and repeat the phrase [phrases] until I play it correctly. On stage, that's not allowed, I play the safest phrases on stage while I'm free on my own."

This tension, which may limit non-conformity, results from the concern about external evaluation. Wassim noted a similar tension when playing with others: "the solo player [in such a situation] has less freedom for the taqsīm."

Moreover, when talking about taqsīm's functions, Wassim noted that tension may occur between the wish to play virtuously and the introductory function of taqsīm:

> "This second function is to highlight the player's skills, while the first function is to support and prepare for the music. Preferably, the player does not play very virtuously [in the first function], so as not to divert full attention from the piece."

This can be described as a tension between recycling and individual agency.

Moreover, Wassim stated:

> "When I play alone, I generally don't have to give a pattern or explain my style, so I don't have to do the same repetitions and I can do fewer repetitions. At the same time, I don't have the crisis [the issue, the question] whether the audience is enjoying it or not. Therefore, I can take long breaks and enter into a situation that is closer to the dialogue with the self and a Sufi process. . . Meditation through the music – I try to keep that away from the stage, especially at concerts when there is a mixed audience of different cultures. I try to make the taqsīm clear and understandable for the wider audience. This is because I will lose a part of the audience if I radicalize my music in any direction [being too meditative, or making it so clear]. But when I am alone, I can go in the direction I want and without losing anything."

Wassim's statement shows that he might experience a tension between the wish of entering a meditative state, where his music cannot be completely understood or followed by his listeners, and trying to keep his music clear and concentrated at the price of not entering such a meditative state. This can be described as a tension between agency, non-conformity, and flow on the one hand and with the concern about external evaluation on the other. The participants' answers show that tension may appear between many different components: between recycling and novelty, freedom and limitation, the artistic expression of the moment and the coherence of the concert program etc.

CONCLUSION

The aim of this study was to shed light on taqsīm as a creative process from a transcultural point of view. The interviews with the three Berlin-based oud players from Syria revealed that taqsīm is a kind of instant composition with a flexible form that highlights the technical skills of the player and/or serves as an introduction for pre-composed music. Moreover, it serves as a space for interaction between the musicians, the audience and the pre-composed music. Taqsīm is learned by imitation and experimenting, and contains recycled musical materials from maqam music amongst others. The migratory situation enabled our participants to have new musical experiences and to integrate new musical materials, playing techniques and esthetic values into their taqsīm. Their contact with various musical genres in Berlin—in addition to experiencing diverse concert audiences—gave our participants new opportunities to negotiate the boundaries of taqsīm. We mapped the codes and themes of the thematic content analysis onto Hill's cross-cultural experiential model of musical creativity. This mapping showed that: (1) generativity in taqsīm is goal-oriented. Generating taqsīm aims to create room for individual artistic expression, for interaction with the audience, and to support and introduce the pre-composed pieces. (2) Due to the freedom of taqsīm, and due to its role in showing the technical skills of the musicians, taqsīm allows the players to interact as active agents. (3) There is interaction with the audience, other musicians, and with the music itself. (4) The participants were seeking to integrate non-traditional elements in their own taqsīm. (5) It is a common practice to use recycled materials when playing taqsīm. (6) A state of flow or meditative experience when one forgets the surrounding may appear when playing taqsīm. Some of the tensions that may appear between the different components of Hill's model were evident, too, in our analysis of the interviews. Such tensions may appear between recycling and novelty, freedom and limitation, the artistic expression of the moment and the coherence of the concert program.

Hill's model of creativity—which highlights the components of generativity, agency, interaction, non-conformity, recycling, and flow—may facilitate positioning, linking, and comparing taqsīm with other musical genres and cultures. Such a theoretical framework provides the opportunity to investigate general features that characterize many creative musical practices without denying the specific details of each genre. The multidimensional view of taqsīm as a creative practice with multiple components appears to be more fruitful in capturing the full breadth of this musical practice than placing it on an improvisation-composition continuum. We envisage that having applied Hill's model in this study will further open up pathways for incorporating transcultural musical processes in the study of creativity.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

ZA and MBK developed the idea and design of the study. ZA conducted the interviews, analyzed the data, and produced the first draft. MBK provided substantial comments and assisted with the argument development. Both authors approved the final version of the manuscript.

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REFERENCES

Auh, M.-S. (1997). Prediction of musical creativity in composition among selected variables for upper elementary students. *Bull. Council Res. Music Educ.* 133, 1–8. doi: 10.2190/ec.40.1.a

Ayari, M., and McAdams, S. (2003). Aural analysis of Arabic improvised instrumental music (Taqsīīm). *Music Percept.* 21, 159–216. doi: 10.1525/mp.2003.21.2.159

Baer, J. (2015). The importance of domain-specific expertise in creativity. *Roeper Rev.* 37, 165–178. doi: 10.1080/02783193.2015.1047480

Baily, J., and Collyer, M. (2006). Introduction: music and migration. *J. Ethnic Migrat. Stud.* 32, 167–182.

Beaty, R. E., Smeekens, B. A., Silvia, P. J., Hodges, D. A., and Kane, M. J. (2013). A first look at the role of domain-general cognitive and creative abilities in jazz improvisation. *Psychomusicol. Music Mind Brain* 23, 262–268. doi: 10.1037/a0034968

Bishop, L. (2018). Collaborative musical creativity: how ensembles coordinate spontaneity. *Front. Psychol.* 9:1285. doi: 10.3389/fpsyg.2018.01285

Boyatzis, R. E. (1998). *Transforming Qualitative Information: Thematic Analysis and Code Development*. Thousand Oaks, CA: Sage.

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101. doi: 10.1191/1478088706qp063oa

Burnard, P. (2012a). *Musical Creativities in Practice*. Oxford: Oxford University Press.

Burnard, P. (2012b). "Rethinking "musical creativity" and the notion of multiple creativities in music," in *Musical Creativity: Insights From Music Education Research*, ed. O. Odena (Aldershot, Hants: Ashgate Publishing, Ltd.), 5–28.

Campbell, P. S. (1990). Crosscultural perspectives of musical creativity. *Music Educ. J.* 76, 43–46. doi: 10.2307/3401077

Clarke, E. F., and Doffman, M. (eds) (2017). *Distributed Creativity: Collaboration and Improvisation in Contemporary Music*, Vol. 1. Oxford: Oxford University Press.

Crow, B. (2008). Changing conceptions of educational creativity: a study of student teachers' experience of musical creativity. *Music Educ. Res.* 10, 373–388. doi: 10.1080/14613800802280126

Csikszentmihalyi, M. (1996). *Creativity: Flow and the Psychology of Discovery and Invention*. New York, NY: HarperPerennial.

Deliège, I., and Wiggins, G. A. (2006). *Musical Creativity: Multidisciplinary Research in Theory and Practice*. Hove: Psychology Press.

Glăveanu, V. P. (2019). Measuring creativity across cultures: epistemological and methodological considerations. *Psychol. Aesthet. Creat. Arts* 13, 227–232. doi: 10.1037/aca0000216

Goldman, A. L. (2019). *Beyond the Continuum: Towards a Typology of Improvisatory Processes*. Available online at: https://legacy.societymusictheory.org/files/2019_handouts/goldman-handout-0044.pdf (accessed November 25, 2020).

Hargreaves, D. J. (2012). Musical imagination: perception and production, beauty and creativity. *Psychol. Music* 40, 539–557. doi: 10.1177/0305735612444893

Hargreaves, D. J., Hargreaves, J. J., and North, A. C. (2011). "Imagination and creativity in music listening," in *Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance and Perception*, eds D. Hargreaves, D. Miell, and R. MacDonald (United Kingdom: Oxford University Press) pp. 156–172. doi: 10.1093/acprof:oso/9780199568086.003.0010

Hayes, N. (1997). *Theory-led Thematic Analysis: Social Identification in Small Companies*. Hove: Psychology Press.

Hill, J. (2018). *Becoming Creative: Insights from Musicians in a Diverse World.* New York, NY: Oxford University Press.

Karlsen, S. (2011). Using musical agency as a lens: researching music education from the angle of experience. *Res. Stud. Music Educ.* 33, 107–121. doi: 10.1177/1321103x11422005

Kenny, A. (2014). 'Collaborative creativity'within a jazz ensemble as a musical and social practice. *Think. Skills Creat.* 13, 1–8. doi: 10.1016/j.tsc.2014.02.002

Kim, J.-A. (2017). » Cross-cultural music making «: concepts, conditions and perspectives. *Int. Rev. Aesthet. Sociol. Music* 48, 19–32.

Lehmann, A. C. (2005). "Komposition und improvisation: generative musikalische performanz [Composition and improvisation: generative musical performance]," in *Allgemeine Musikpsychologie*, eds T. H. Stoffer and R. Oerter (Göttingen: Hogrefe), 913–954.

Lehmann, A. C., and Kopiez, R. (2002). "Revisiting composition and improvisation with a historical perspective," in *Proceedings of the 10th Anniversary Conference of the European Society for the Cognitive Sciences of Music (ESCOM): Musical Creativity, Liège, Belgium*, Citeseer, 5–8.

Lehmann, A. C., and Kopiez, R. (2010). The difficulty of discerning between composed and improvised music. *Music. Sci.* 14, 113–129. doi: 10.1177/10298649100140s208

Marcus, S. L. (1993). Solo instrumental improvisation (Taqāsīm) in Arab Music. *Middle East Stud. Assoc. Bull.* 27, 108–111. doi: 10.1017/s0026318400027127

Mazzola, G., Park, J., and Thalmann, F. (2011). *Musical Creativity: Strategies and Tools in Composition and Improvisation*. Berlin: Springer Science & Business Media.

Nagy, Z. (2016). *Embodiment of Musical Creativity: The Cognitive and Performative Causality of Musical Composition*. Abingdon: Taylor & Francis.

Nettl, B. (1974). Thoughts on improvisation: a comparative approach. *Music. Q.* 60, 1–19. doi: 10.1093/mq/lx.1.1

Nettl, B., and Riddle, R. (1973). Taqsim Nahawand: a study of sixteen performances by Jihad Racy. *Yearbook Int. Folk Music Council* 5, 11–50. doi: 10.2307/767493

Nooshin, L. (2017). "(Re-) imagining improvisation: discursive positions in Iranian music from classical to jazz," in *Distributed Creativity: Collaboration and Improvisation in Contemporary Music*, eds E. F. Clarke and M. Doffman (Oxford: Oxford University Press).

Odena, O., and Welch, G. (2012). "Teachers' perceptions of creativity," in *Musical Creativity: Insights from Music Education Research*, ed. O. Odena (Farnham: Ashgate), 29–48.

Peterson, E. M. (2006). Creativity in music listening. *Arts Educ. Policy Rev.* 107, 15–21. doi: 10.3200/aepr.107.3.15-21

Pressing, J. (1984). Cognitive processes in improvisation. *Adv. Psychol.* 19, 345–363. doi: 10.1016/s0166-4115(08)62358-4

Racy, A. J. (1991). Creativity and ambience: an ecstatic feedback model from Arab music. *World Music* 33, 7–28.

Racy, A. J. (2000). The many faces of improvisation: the Arab Taqāsīm as a musical symbol. *Ethnomusicology* 44, 302–320. doi: 10.2307/852534

Rose, S., MacDonald, R., and Collins, D. (2012). "Improvisation as real-time composition," in *The Act of Musical Composition: Studies in the Creative Process*, ed. D. Collins (London: Ashgate Publishing), 187–213. doi: 10.4324/9781315612256

Sarath, E. (1996). A new look at improvisation. *Journal of Music Theory* 40, 1–38. doi: 10.2307/843921

Sawyer, R. K., John-Steiner, V., Csikszentmihalyi, M., Moran, S., Feldman, D. H., Gardner, H., et al. (2003). *Creativity and Development*. New York, NY: Oxford University Press.

Schiavio, A., and Benedek, M. (2020). Dimensions of musical creativity. *Front. Neurosci.* 14:1208. doi: 10.3389/fnins.2020.578932

Shannon, J. H. (2003). Emotion, performance, and temporality in Arab music: reflections on Tarab. *Cult. Anthropol.* 18, 72–98. doi: 10.1525/can.2003.18.1.72

Sloboda, J. A. (1986). *The Musical Mind*. Oxford: Oxford University Press.

Solis, G., and Nettl, B. (2009). *Musical Improvisation: Art, Education, and Society*. Champaign, IL: University of Illinois Press.

Sorce Keller, M., and Barwick, L. (eds) (2012). "Thoughts on music and migration," in *Italy in Australia's Musical Landscape*, (Melbourne: Lyrebird), 225–231.

Touma, H. H. (1971). The maqam phenomenon: an improvisation technique in the music of the Middle East. *Ethnomusicology* 15, 38–48. doi: 10.2307/850386

Van der Schyff, D., Schiavio, A., Walton, A., Velardo, V., and Chemero, A. (2018). Musical creativity and the embodied mind: exploring the possibilities of 4E cognition and dynamical systems theory. *Music Sci.* 1:2059204318792319.

Villarreal, M. F., Cerquetti, D., Caruso, S., Schwarcz López, Aranguren, V., Gerschcovich, E. R., et al. (2013). Neural correlates of musical creativity: differences between high and low creative subjects. *PLoS One* 8:e75427. doi: 10.1371/journal.pone.0075427

Watson, C. (2012). *How Musicians Develop the Ability to Improvise: A Cross-Cultural Comparison of Skill Development in the Egyptian, Hindustani Classical, and Jazz Traditions*. PhD Dissertation. Sydney NSW: University of New South Wales.

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SYSTEMATIC REVIEW
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Creative Collaboration and Collaborative Creativity: A Systematic Literature Review

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Studies of creativity emerging from cultural psychology and social psychology perspectives challenge individualist conceptions of creativity to argue that social interaction, communication, and collaboration are key elements in creativity. In recent work creative collaboration has been proposed to be “distributed” between audiences, materials, embodied actions, and the historico-socio-cultural affordances of the creative activity and environment, thus expanding the potentialities of creative collaboration beyond instances of direct human interaction and engagement. Music performance, improvisation and composition may be viewed as exemplary “laboratories” of creative collaboration through the combined elements of audiences, materials, embodied actions and historico-socio-cultural affordances and constraints. This article reports the findings of a systematic literature review of creative collaboration and collaborative creativity in music. We sought to identify what has been currently investigated in relation to these terms and concepts in music, with what methodologies and in what settings. Findings indicate that studies were undertaken in higher education, professional development and professional practice predominantly, leading to an emergent phenomenon of interest, collaborative creative learning. Musical genres were jazz, popular, western classical, contemporary and world musics across the musical processes of composing, improvising and performing. Studies in higher education and professional development settings focused on identifying those practices that supported learning rather than the nature of collaborative creative approaches or the outcomes of creative collaboration. Participants were primarily male, with small sample sizes. Methodologies were largely qualitative with an emphasis on case study using observation, interview and reflective diary methods. Further areas for research include: the investigation of gendered approaches to creative collaboration, collaborative creativity, and collaborative creative learning; the use of more diverse research methodologies and methods and techniques including large-scale quantitative studies and arts-based and arts-led approaches; and the investigation of more diverse music settings.

Keywords: creative collaboration, collaborative creativity, collaborative creative learning, distributed creativity, cultural psychology, music performance, improvisation, composition

BACKGROUND

Studies of creativity emerging from cultural psychology (Glaveanu, 2010a,b; Barrett et al., 2014; Glaveanu et al., 2014) and social psychology theoretical frameworks (Miell and Littleton, 2004; MacDonald et al., 2005) increasingly challenge individualist conceptions of creativity to argue that social interaction, communication, and collaboration are key elements in creative thought and practice. Vera John -Steiner's seminal work *Creative Collaboration* published in 2000 identifies a number of contributing factors for the turn from an individualist Western focus on the solitary creative genius to a social constructivist view of creativity. These factors include the waning of Piagetian views of learning and development in the second half of the 20th century as Vygotsky's writings from the 1920–1930s Soviet era became known in the English-speaking world through translation (Vygotsky, 1978, 1986), and the take up of cultural psychology as a theoretical framework for learning and development (see for example Bruner, 1996; Cole, 1996). Whilst others had explored creativity as a social rather than individual phenomenon in earlier work (Amabile, 1983), arguably, the notion of active co-contribution to creative production was explored in depth for the first time in John-Steiner's volume.

John-Steiner's focus was on intellectual and artistic collaboration as evidenced in long-standing creative partnerships. Drawing on Howard Becker's notion of "art worlds" (Becker, 1982), she identified the ways in which complementarity, mutuality, interdependence, and joint activity underpinned creative work. For John-Steiner, "*humans come into being and mature in relation to others*" (2000, p. 187, John-Steiner's italics). Collaboration thus "…provides a mutual zone of proximal development where participants can increase their repertory of cognitive and emotional expression" (p. 187). John-Steiner presents a model of creative collaboration which identifies four patterns of collaboration: distributed, complementary, family, and integrative. Distributed collaboration is that which occurs in shared thought communities, or loose networks of collaborative groups, where ideas and practices may be shared and appropriated for individual as well as for collective ends. Complementary collaborations rest in the recognition and instrumentalization of complementary expertise, disciplinary knowledge, roles and temperaments to pursue a common goal (2000). Family collaborations, whilst nested in the notion of familial relationships (e.g., life-partners), focus on the ways in which relationships, roles and responsibilities may shift between members over time and between tasks. Importantly, these collaborations rely on a heightened sense of mutual obligation, shared companionship, and belonging, as well as a capacity to survive or manage productively the tensions, conflicts, and disagreements that might arise through collaborative work. John-Steiner's fourth pattern of collaboration, integrative collaboration is created in and built upon joint endeavors to effect "transformative change." She emphasizes that these four patterns of creative collaboration are not hierarchical; rather, they serve different ends in producing creative work.

Whilst early investigations of creative collaboration emphasized the role of social interaction in creative collaboration (John-Steiner, 2000), more recent work in creative collaboration has expanded the notion of "distributed creativity" (Glaveanu, 2014) to encompass interactions between creator and audiences, materials, embodied actions, and the historico-socio-cultural affordances of the creative activity and environment. This approach simultaneously expands the potentialities of creative collaboration beyond instances of direct human interaction and engagement and reminds us that multiple human interactions at various removes across time and space underpin any creative endeavor.

In the above we have focused on creative collaboration as the key concept. Whilst collaborative creativity might be viewed merely as a synonym for creative collaboration, the reversal of emphasis may offer opportunity for differing perspectives to emerge. For example, in foregrounding the term "collaborative" the emphasis is placed on the role of the groups and teams (Sawyer, 2017; Paulus and Nijstad, 2019) in producing creative outcomes rather than the outcomes themselves. Research in this area, often undertaken in industry and innovation contexts (Mumford, 2012), seeks to identify the intra- and inter-personal, environmental, and socio-cultural factors that contribute to effective teamwork, group and organizational creativity.

Delalande, whilst acknowledging the "eminently solitary" nature of "Western erudite music" reminds us that music creation also has a long history of collaborative practice. He notes

> …throughout the time when the technology of writing dominated the practice of Western erudite music—roughly since the 13th century—creation was an eminently solitary activity, which has not been the case within the oral tradition (since creation in the oral tradition comes about in the very course of transmission). (2016, p. 457)

He writes of the "compelled cooperation" of teams, whether "direct or indirect" (what might also be viewed as distributed), illustrating the work of collaborative creative teams in music through reference to the work of GRM (Groupe de Recherches Musicales) and IRCAM (Institute de Recherche et Coordination Acoustique/Musique). This work is described as respectively "cooperation" between several composers, between tool developers and composers, and, between musical assistants and composers. Whilst the focus here is on composer-focused collaborative creativity, others recognize the roles of performers including performers and conductors (Ravet, 2016), performers and composers (Bayley and Lizée, 2016), and performers and audiences (Freeman and Godfrey, 2010) as sites for collaborative creativity. This body of research demonstrates an increasing interest in collaborative creative music practices in the western classical music profession, and a move away from the notion of creativity being the preserve of the solitary genius (Sawyer, 2017).

We suggest that music performance, improvisation and composition may be viewed as exemplary "laboratories" of creative collaboration and/or collaborative creativity through the historico-socio-cultural affordances (or constraints) they offer and the combined elements of audiences, materials, embodied actions and the collaborative teams that are involved (composers, performers, conductors, tool developers, music assistants etc.). It is notable that the research "laboratories" cited above have focused largely on "eminence" settings (see Gardner, 1993; Csikszentmihalyi, 1996), that is, those settings which provide a means to tap the knowledge and expertise of leaders and professionals in a specific field (Barrett, 2006; Barrett and Gromko, 2007). Ericsson endorses this approach and "… rejects the assumption that data on large samples of beginners can be extrapolated to samples of elite and expert performers" (Ericsson, 2014, p. 81). He argues for "expert-performance" approaches to investigations of advanced skills and knowledge. Accordingly, the study of these laboratories raises possibilities not only for the discipline of music but also holds potential for other domains of creative collaborative practice. In what follows we report the findings of a systematic literature review of collaborative creativity and creative collaboration in music, focusing on "eminence" settings of practice including teaching and learning. Our investigation was guided by the following questions:

(1) How and in what eminence music settings has creative collaboration or collaborative creativity been investigated?
(2) What problems and research questions have been the focus of research in those settings?
(3) How are creative collaboration and/or collaborative creativity described, defined and framed in eminence music settings?
(4) What are the practical implications of research concerned with creative collaboration and/or collaborative creativity in eminence music settings?

METHODOLOGY

Our approach to conducting the systematic literature review was guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist (Moher et al., 2009). This provides guidelines for developing search protocols, searching data bases, selection of studies, analysis of relevant characteristics, and synthesis of results. The full-text articles were coded using SPIDER [Sample, Phenomenon of Interest, Design, Evaluation (i.e., key findings), Research type] tool developed by Cooke et al. (2012) for synthesis of qualitative evidence. In this section of the paper we provide an outline of our use and implementation of this approach to a systematic literature review, including the development of the search protocol and the procedures for first and second screening.

Developing the Search Protocol

Prior to undertaking the search of data bases, and in accordance with an iterative approach (Moher et al., 2009), an exploratory search was undertaken to ascertain the timeline for when the research on the topic has been published. Using a university library search engine keywords "creative collaboration," "collaborative creativity," "collaboration," and "creativity" were combined with "in music" and with "and music" to explore *when* academic publications on this topic began to appear. In addition, the team had brainstormed possible keywords for the main search and these were confirmed by the exploratory screening. The following search protocol for the main search was adopted:

Line 1—(Collaborat* or team* or share* or reciproc* or mutual* or intersubjectiv* or collective or empath* or entrain* or attun* or system* or group or ensemble or social or distributed).
Line 2—(creative* or new or innovat* or original* or novel* or problem-solv* or problem-find* or flow or improv* or emergent).
Line 3—(pedagog* or apprentice* or leader* or mentor* or guid* or teach* or learn* or practice or master*).
Line 4—(music).

First Search and Screening

Three data bases (Web of Science, ERIC and JSTOR) were searched using the combined keywords of the search protocol, in English, published between 1990 and 2021, searching under Topic/All fields for peer-reviewed journal articles with output by relevance. Parameters were set in order to limit the results to papers published in English as the shared language of all team members; published since 1990 because exploratory screening had identified no publications before 1990 and only a handful of papers in the 1990s, and with a cut-off at 2021 as the date when this research was carried out; searching under "Topic (Web of Science)/All fields (JSTOR)/Search anywhere (ERIC)" was adopted when an "Abstract" search resulted in zero outputs in some data bases; book chapters were eliminated from the search as these frequently synthesize existing literature rather than report on new research, with peer-reviewed articles typically undergoing a more stringent peer review process.

The search identified 6,347 items and after the first screening and removal of duplicates, 138 items were deemed relevant according to the first screening criteria.

First screening criteria:

- In English;
- Published between 1990 and 2021;
- Peer-reviewed journal articles;
- Context of music;
- Creativity and/or collaboration as either key concept.

Second Screening

Abstracts of the 138 retained articles were screened by one team member and main points summarised under the following topic areas: composition (technology and traditional methods), teacher education/higher education/professionals, theoretical papers, inter-disciplinary papers, jazz/popular music, brain studies, community music, and improvisation. Papers concerned with primary or secondary school contexts were excluded (n = 26) due to our focus on eminence settings, leaving 112 papers (see **Table 1** and **Figure 1**).

Retained Papers

The full team (three researchers) screened the 112 retained papers (titles and abstracts only) independently and after discussion 57 papers were excluded according to the following criteria for retention:

TABLE 1 | Screening criteria.

	Search engine	Keywords	Language	Dates	Filters
Exploratory Search	University library	• Collaborative creativity and music • Collaborative creativity in music • Creative collaboration and music • Creative collaboration in music • Creativity in music • Collaboration in music	English	1980–2021	• Peer-reviewed journals • Journal articles • Books • Book chapters • By relevance
First search and screening	• Web of Science • ERIC • JSTOR	Lines 1–4 of search protocol combined	English	1990–2021	• Topic/All fields/Search anywhere • Peer-reviewed articles • Music context • Creativity and collaboration as either key concept
Second screening			English	1990–2021	• Abstract screening • Exclude primary and secondary education

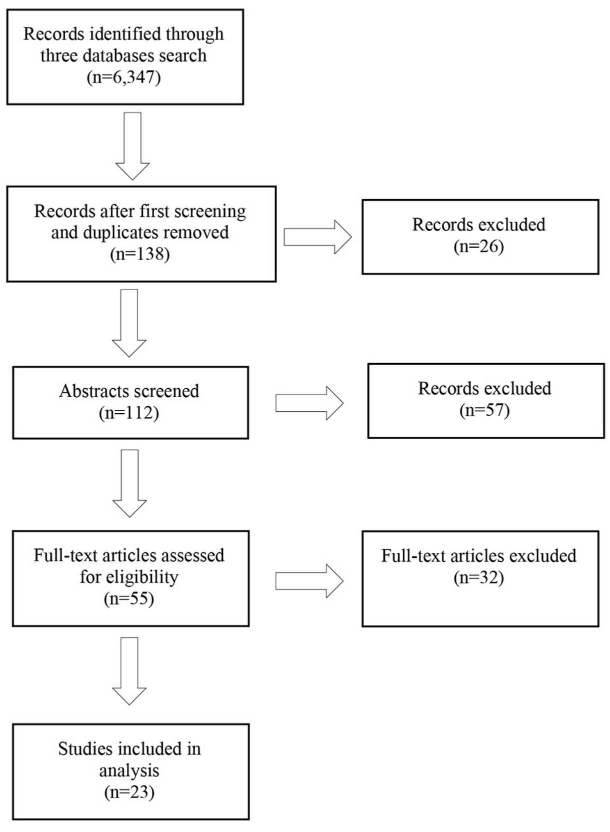

FIGURE 1 | Flow-chart of the screening process.

- Context: Professional training and practice in music performance, improvisation and composition, where "creative collaboration" or "collaborative creativity" is a primary focus
- Peer-reviewed journal article
- In English
- Empirical study
- Both key concepts of creativity and collaboration are the focus of study

Papers were excluded at this stage if all three team members agreed. Papers where there was disagreement were retained at this stage.

An analysis of the full texts of the remaining 55 articles was carried out. The articles were read by the researchers and coded using the SPIDER tool developed by Cooke et al. (2012) (see **Table 2**). The original categories were adapted to the music context through iterative team discussions during the coding process.

Theoretical papers ($n = 5$) were retained for the Background section and only empirical papers were considered for full-text analyses ($n = 23$) (see **Figure 1**).

Twenty-three papers were retained for analysis, while 32 were excluded. Five of these papers informed the theoretical background to the systematic review but were not included in the analysis as they were not empirical papers. Reasons for exclusion from analysis were: exclusive focus on one concept (either creativity or collaboration) rather than the combined concept (creative collaboration or collaborative creativity) and non-empirical papers.

Publication years ranged from 2006 to 2020. Seven studies were carried out in Australia and six studies were carried out in the UK. A further three studies were undertaken in the USA and one in Canada. Six studies were undertaken in European countries: Italy (two studies), Denmark, Finland, Ireland and Spain, and one in Singapore (**Table 3**).

Addressing Issues of Quality and Bias

As noted above the analysis was guided by the PRISMA checklist (Moher et al., 2009). We also drew on the JBI Systematic Reviews Checklist for Qualitative Research (Joanna Briggs Insitute, 2017) to address issues of quality and bias. In accordance with both these guidelines, we worked as a team of three, with each member reading every paper and subsequently discussing each paper (via

TABLE 2 | SPIDER tool [adapted from Cooke et al. (2012) to the study's context].

SPIDER	Justification
S—sample	Participants in higher education, professional development, professional training, and practice in music performance, improvisation, and composition, where "creative collaboration" or "collaborative creativity" is a primary focus
PI—phenomenon of interest	Creative collaboration or collaborative creativity in music
D—design	Methods: establishing credibility, transferability, reliability, and validity issues
E—evaluation	Outcomes/Key findings: music processes; interpersonal processes; intrapersonal processes; pedagogy and facilitation; definitional
R—research type	Qualitative or Quantitative or Mixed methods (open) paradigm

TABLE 3 | Geographical distribution of papers retained for analysis.

		Region						Total
		Australia	Canada	USA	Europe	Asia	UK	
Publication year	2006	1	0	0	0	0	1	2
	2007	0	0	2	0	0	0	2
	2011	0	0	1	0	0	0	1
	2012	2	0	0	0	0	1	3
	2014	0	0	0	2	0	0	2
	2015	0	0	0	1	0	1	2
	2016	1	0	0	1	0	1	3
	2017	0	0	0	1	0	1	2
	2018	1	1	0	1	0	0	3
	2019	2	0	0	0	0	0	2
	2020	0	0	0	0	1	0	1
Total		7	1	3	6	1	5	23

regular zoom meetings), in order to establish that we were in agreement that each paper met our inclusion critieria. Given that 22 of the 23 papers retained for analysis were qualitative studies our critical appraisal of the papers focused on the qualitative markers of methodological rigor, including credibility, transparency and trustworthiness (Lincoln and Guba, 1985), and examined congruity between philosophical perspective and research methodology, methodology and research questions and objectives, methodology and methods, representation and analysis of data, and interpretation of results (Joanna Briggs Insitute, 2017). Discussions also addressed issues of researcher reflexivity, participant voice, ethical processes, and conclusions.

Some methodological limitations among the retained papers were noted (**Table 4**). For example, while all 23 of the papers provided sufficient detail about the cultural and theoretical location of the research, four of the 23 papers did not discuss explicitly the influence of the researcher in the interpretation of the data. A further five papers, while not explicit in discussing this point, did address this issue by demonstrating how findings had been triangulated. For three practice-based artistitic research studies this issue was deemed to be not applicable. One methodological concern among this group of papers rests in the ways in which ethical issues were reported. Only six papers included explicit detail concerning ethics review board approval or informed consent procedures. However, a further 17 papers did provide sufficient information to be able to ascertain that the study had been carried out in an ethically responsible manner, particularly with respect for consent, confidentiality and anonymity. One further potential limitation of the findings reported lies in the small sample sizes which are a feature of qualitative approaches. Nevertheless, such studies offer a depth and richness of data and analysis that yields findings that may be transferred to other settings.

In addition to the appraisal points reported in **Table 4**, the retained quantitative papers were deemed to include sufficient information when evaluated against a further set of criteria that included: (1) criteria for inclusion of participants; (2) the context explained fully; (3) the reliability and validity of approaches to measurement; (4) transparency with regard to confounding variables; (5) appropriate statistical analyses. These papers were found to fulfill each one of these criteria.

Notwithstanding the noted limitations, the researchers reached consensus in each instance, agreeing that each paper was sufficiently rigorous for inclusion in the review. Finally, as a further consideration of quality, through establishing publication in a refereed journal as an inclusion criterion, each article retained for analysis had already been submitted to a rigorous quality appraisal through the academic peer review process. Therefore, no further papers were excluded following critical appraisal of the methodological rigor.

FINDINGS

How and in What Eminence Music Settings Has Creative Collaboration or Collaborative Creativity Been Investigated?

Settings

Eight studies took place in higher education music disciplines including performance (one study), improvisation (four studies), composition (two studies) and recording studio practice (one study). Fourteen studies were carried out in professional music contexts, with eight of those concerned with an analysis of professional practice and five focused on processes associated with professional development. Among the professional development studies, two focused on developing expertise in improvisation, two focused on composition and one was undertaken in the context of recording studio practice. Finally, two further studies took place in community settings, where the focus was on improvisation (**Table 5**).

TABLE 4 | Criteria for assessment of methodological rigor.

Criteria	Number of papers in each evaluation category			
	Yes	No	Not clear	Not applicable
Congruity: philosophical perspective with methodology	23			
Congruity: methodology with research question	23			
Congruity: methodology with data collection methods	23			
Congruity: methodology with analysis and representation of data	23			
Congruity: methodology with interpretation of results	23			
Researcher positionality: cultural and theoretical location of research	23			
Influence of the researcher	11	4	5	3
Participant voice represented	22			1
Ethics	6		17	

TABLE 5 | Settings for the research.

		Performance	Improvisation	Composition	Recording studio practice	Total
Setting	Higher education	1	4	2	1	8
	Professional development	0	2	2	1	5
	Professional practice	3	4	1	0	8
	Community	1	1	0	0	2
Total		5	11	5	2	23

Table 6 shows the musical genres that characterized the research studies. The greatest number of studies were carried out in the context of jazz (10 studies), with seven out of those 10 studies located in professional contexts. In contrast, world music was represented in just one study carried out in a community context. Five studies concerned Western classical music-making, with two of those focusing on professional performance and a further three focusing on improvisation or composition in higher education settings. Two studies were carried out in the context of popular music in higher education, while a further four studies focused on popular music in professional contexts. Finally, contemporary art music formed the context for two further studies, one focusing on improvisation and the other on performance.

Sample

Twenty-two of the 23 studies reported their sample size, and overall, this ranged from 1 to 64, with a mean sample size of 13.86. Just seven studies reported the ages of their participants, which overall ranged from 17 to 55. The mean participant age range among those seven studies was 27–39. Fourteen studies reported that their research included male participants, while 10 of those 14 studies also included female participants. Overall, of the 14 studies that reported the sex of their participants, a total of 72 males were included in the research compared with 32 females.

What Problems and Research Questions Have Been the Focus of Research in Those Settings?

Professional Development

Among the studies concerned with professional development, Biasutti (2015, 2018) used video observations and in-depth interviews to explore the development of expertise in collaborative online composition. This study analyzed communication modes and learning strategies among three professional electronic band musicians who had previously only collaborated in offline environments. Likewise framed with a strong focus on professional development, Brinck (2017) used ethnographic methods to capture how learning to jam can emerge through situated learning practice. In a similar vein, de Bruin (2016, 2019) used a phenomenological approach to explore elite improvisation performers' lived experiences of evolving creative improvisation practices.

Professional Practice

Studies of professional practice differed from those exploring professional development through their emphasis on understanding the nature of creative collaborative processes rather than on the practices that supported learning. For example, Hill and Fitzgerald (2012) adopted a participant-observation approach in exploring creative professional practice, with a focus on understanding how musical and interpersonal interactions among live electronica musicians contributed to a coherent musical performance. Also, in the context of performance, the interpersonal dimensions of control and trust were the focus of Khodyakov's (2007) study that used in-depth interviews and observations to explore the creative and collaborative professional practices within a conductorless contemporary orchestra. With a similar focus on the intersection of interpersonal interaction with collaboration and creativity in professional practice, Hill et al. (2018) carried out a reflective, participant observation analysis of the role of conflict among band members engaged in collaborative composition.

Morgan et al. (2015) investigated interpersonal behaviors in the context of professional improvisation. In this study, the researchers used electronic sensors, video and self-report

TABLE 6 | Musical genres represented in the research.

Setting		Musical genre					Total
		Contemporary	Popular	Jazz	Western classical	World	
HE	Performance	0	1	1	0		2
	Improvisation	1	0	2	1		4
	Composition	0	0	0	2		2
	Recording studio practice	0	1	0	0		1
	Sub-Total	1	2	3	3		9
Professional development	Improvisation		0	2			2
	Composition		2	0			2
	Recording studio practice		1	1			2
	Sub-Total		3	3			6
Professional practice	Performance	1	0	0	2		3
	Improvisation	0	0	4	0		4
	Composition	0	1	0	0		1
	Sub-Total	1	1	4	2		8
Community	Performance			0		1	1
	Improvisation			1		0	1
	Sub-Total			1		1	2
	Total	2	6	11	5	1	25*

**Total is >23, because some studies were multi-genre.*

measures to explore relationships between non-verbal behaviors (e.g., gaze, posture), physiological response (e.g., heart rate), and facets of the musical process such as creative decisions. Musical interactions within ensembles, as compared with solo settings, were explored by Marchini et al. (2014), who used computer modeling to investigate how inter-voice dependence may be related to musical expressivity. Taking a slightly different approach to exploring professional practice, other researchers (MacDonald and Wilson, 2006; Wilson and MacDonald, 2012, 2017) have interrogated the way professional jazz musicians use language (in the context of interviews and focus groups) to construct musician identity and a professional discourse about improvisation.

Higher Education

Among the studies in higher education, seven were carried out with undergraduate students, while just one was carried out in a Doctoral Studies program, focusing on recording studio practice.

Within higher education, van Nort (2018) carried out a piece of practice-based research using participant observation to explore intersubjectivity within an electroacoustic orchestra performance where the music-making was guided by a form of improvised conducting known as Sound-painting. With a similar interest in electronic music contexts, Freeman and Van Troyer (2011) explored processes associated with real-time creativity, or the fusion between improvisation and composition. Using a process known as Laptop Orchestra Live Coding, this practice-based study analyzed musical interactions represented in text-based computer code among members of a laptop orchestra.

Collaborative learning within intensive workshops has been explored. For example, situated and collaborative learning experienced within jazz and popular music conservatoire performance workshops was investigated by Virkkula (2016). Using a case study approach and gathering data via students' reflective journal entries, Virkkula investigated the processes of sociocultural learning within workshops structured as communities of musical practice comprising students and professional musicians. In a similar vein, de Bruin et al. (2019) explored collaborative learning that emerged from authentic, "real-world" rehearsal, workshop and performance opportunities where jazz students collaborated alongside professionals. The researchers used in-depth interviews pre- and post-three rehearsal/workshop/performance cycles, prompting students to reflect on the role of collaboration in their learning. Collaborative learning was also investigated by Blom (2012), who, in this instance, used open-ended questionnaires to gather insights about the learning that occurred within interdisciplinary (music, dance, drama) and collaborative improvisation workshops.

One-to-one contexts have also been the focus of research concerned with collaborative creativity and collaborative creative learning, in higher education. For example, learning and teaching in creative composition, occurring within one-to-one dyads have been explored (Barrett, 2006; Barrett and Gromko, 2007) using in-depth interviews and video observation to explore the collaborative processes between student-composer and composer-teacher. One-to-one peer learning in composition was the context for a subsequent study carried out by Dobson and Littleton (2016). In this study, video and audio recordings of the students' collaborative work was analyzed, looking at micro-moments where "collaborative conceptual creative themes" (p. 337) were articulated.

Community Contexts

Finally, two studies were carried out in community contexts. In the first (Kenny, 2014), the research adopted a participant observer role over a 9-month period, and gathered observations, interviews and reflections concerned with collaborative creativity in the context of a non-formal jazz ensemble, where adult participants were supported by eminent expert tutors. The second community-based study (Tan et al., 2020) used in-depth interviews to explore the relevance of creative collaboration in relation to the phenomenon of flow, as experienced by adult participants of a non-formal gamelan ensemble.

Research Designs

Eighteen of the retained studies were designed within a qualitative paradigm, including ethnography (1), case study (11), qualitative exploratory (2), practice-based artistic research (2), and phenomenological studies (2). Two studies were classified as quantitative, and three used mixed methods (**Table 7**).

Research Methods

Among the 23 retained studies, the most frequently used method was semi-structured interview (15 studies), followed by observations (11 studies). In addition, data were gathered through participant observation (five studies), journal reflections (four studies), and audio recordings (four studies). Finally, questionnaires and focus groups were each used in two studies, while computer code analysis was used in one study. **Table 8** shows the methods used within each setting and area of musical practice. In higher education, in-depth semi-structured interviews (four studies), observation and journal reflections (three studies each) were used to the greatest extent. Within professional settings observations and participant observations were used in a total of 11 studies, compared to a total of nine studies using semi-structured interviews.

Across all of the settings, the methods used were primarily qualitative, with the exception of one self-report rating scale questionnaire (Morgan et al., 2015), statistical analyses of features of expressivity extracted from multimodal recordings (Marchini et al., 2014) and quantitative analysis of computer code (Freeman and Van Troyer, 2011). Among the qualitative studies, approaches to analysis included thematic analysis (e.g., Barrett, 2006; Barrett and Gromko, 2007), discourse analysis (MacDonald and Wilson, 2006; Wilson and MacDonald, 2012; Dobson and Littleton, 2016), content analysis (Freeman and Van Troyer, 2011; Virkkula, 2016; de Bruin et al., 2019), interpretative phenomenological analysis (IPA: Wilson and MacDonald, 2017) and finally, the constant comparative method (Blom, 2012; Biasutti, 2015, 2018; Hill et al., 2018).

How Are Creative Collaboration and/or Collaborative Creativity Described, Defined, and Framed in Music Settings?

Phenomenon of Interest

The phenomenon of interest in each paper was examined and coded according to the relative focus on the core concepts of collaboration and creativity. Six papers were framed with a focus on creative collaboration, while a further 10 papers were framed by the idea of collaborative creativity. Eight papers were primarily concerned with collaborative creative learning. Of those concerned with *collaborative creative learning*, six studies were carried out in higher education (Barrett, 2006; Barrett and Gromko, 2007; Blom, 2012; Dobson and Littleton, 2016; Virkkula, 2016; de Bruin et al., 2019) and two in the context of professional development (de Bruin, 2016; Brinck, 2017). Where the phenomenon of interest was conceptualized as *creative collaboration*, one study was carried out in the context of higher education (van Nort, 2018), four studies were located in professional practice contexts (Khodyakov, 2007; Hill and Fitzgerald, 2012; Morgan et al., 2015; Hill et al., 2018), and one was undertaken in a community context (Tan et al., 2020). Finally, among the papers where *collaborative creativity* was the core concept, one study was located in higher education (Freeman and Van Troyer, 2011), three were concerned with professional development (Biasutti, 2015, 2018; de Bruin, 2019), five were concerned with professional practice (MacDonald and Wilson, 2006; Wilson and MacDonald, 2012, 2017; Marchini et al., 2014) and one study was located in a community context (Kenny, 2014) (**Table 9**).

Theoretical Frameworks

Papers were coded in the *creative collaboration* category when their focus was on collaborative processes, with creativity embedded within the collaboration. Studies within this category drew upon sociocultural perspectives (e.g., Khodyakov, 2007), the theory of flow (e.g., Morgan et al., 2015; Hill et al., 2018; Tan et al., 2020) and intersubjectivity (e.g., van Nort, 2018). Key facets of creative collaboration, as discussed in this group of papers, were non-hierarchical approaches, a collectivist mindset where all members of the group have "equal contributional potential" (van Nort, 2018, p. 68) and unpredictable outcomes, alongside the idea of emergent intentionality in creative practice unfolding over time. A feature of creative collaboration is that "the nature and quality of the interactions between ensemble members is a critical determinant of musical outcomes" (Hill and Fitzgerald, 2012, p. 169), or as discussed by Tan et al. (2020), the intersection of relationship, community and peak musical experiences. These intersections may be framed with what Khodyakov (2007, p. 7) refers to as the "chamber paradigm," guided by "the principles of collaboration, equality and democracy" and occurring within a musical context where creative decision-making is distributed among the group. Hill et al. (2018, p. 195) draw attention to "empathetic attunement," as proposed by Seddon (2005), occurring when musicians are able to adopt the perspectives of their co-performers. Similarly, "parallel processing (simultaneous awareness of self and collaborators)," emotional contagion and behavioral mimicry have been highlighted as characteristics of group flow in creative collaboration (Morgan et al., 2015, p. 33). In this vein, creative collaboration may be akin to "improvisational creativity as it manifests in collective musical performance" (van Nort, 2018, p. 68).

Papers coded in the *collaborative creativity* category were primarily focused on creative processes or outcomes, with collaboration positioned as an intersecting process. Within

TABLE 7 | Research designs and paradigms.

	Correlational	Ethnography	Case study	Qualitative exploratory	Practice-based artistic research	Phenomenology	Total
Qualitative	0	1	11	2	2	2	18
Quantitative	1	0	1	0	0	0	2
Mixed	0	0	2	0	1	0	3
Total	1	1	14	2	3	2	23

TABLE 8 | Research methods used within settings.

		Performance	Improvisation	Composition	Recording studio practice	Total number of studies using each method
Higher education	Observation (including video)			2	1	3
	Semi-structured interview		1	2	1	4
	Journal and reflection	1	2			3
	Questionnaire		1			1
	Focus Group		1			1
	Participant observation		1			1
	Computer code analysis		1			1
	Sub-Total	1	7	4	2	14
Professional development	Observation (including video)			2		2
	Audio recording				1	1
	Semi-structured interview		2	2	1	5
	Participant observation				1	1
	Sub-Total		2	4	3	9
Professional practice	Observation (including video)	1	3	1		5
	Audio recording	1	1	1		3
	Semi-structured interview	2	2			4
	Questionnaire		1			1
	Participant observation	2		1		3
	Sub-Total	6	7	3		16
Community	Observation (including video)		1			1
	Semi-structured interview	1	1			2
	Focus group		1			1
	Journal reflections		1			1
	Sub-Total	1	4			5
	Total number of methods used in the 23 studies					43*

**The total number of methods used is >23 because 16 studies used more than one method.*

this category, studies drew on sociocultural perspectives (e.g., Biasutti, 2015, 2018), social constructivist perspectives (e.g., Kenny, 2014), and discursive psychology (e.g., Wilson and MacDonald, 2012), theory of flow (e.g., Marchini et al., 2014) and coregulation (e.g., de Bruin, 2019). Here, the social dimension was conceptualized as being central within the creative process (MacDonald and Wilson, 2006), embedded within "multiple practices and multiple creativities corresponding to music's social and technological mediations" (de Bruin, 2019, p. 30). For example, Freeman and Freeman and Van Troyer (2011, p. 11) describe creative processes as "conversational interactions." Wilson and MacDonald (2012) refer to a spontaneous process characterized by non-verbal interaction, later (Wilson and MacDonald, 2017, p. 137) emphasizing "social creativity" underpinned by shared understandings and mutual engagement. Similarly, Kenny (2014) conceptualizes collaborative creativity as contextualized and communicative, founded upon social and collective processes. As described by Biasutti (2015, p. 118), "the social dimension is intrinsic to creativity and creativity is embedded in interaction."

Within the creative, expressive elements of the music itself, collaborative creativity may be conceptualized as the interplay between "polyphonic expression (each musician plays their melody with possibly a different expression in respect to the one of the other concurrent voices) and inter-dependence among musicians (each musician takes into account information about concurrent voices to shape their expression)" (Marchini et al., 2014, p. 304). Furthermore, in addition to "musical and social

TABLE 9 | Phenomenon of interest in each setting.

	Higher education	Professional development	Professional practice	Community	Total
Creative collaboration	1	0	4	1	6
Collaborative creativity	1	3	4	1	9
Collaborative creative learning	6	2	0	0	8
Total	8	5	8	2	23

practices," sustained engagement in collaborative musical creative practices may involve "leadership and participatory membership and a challenge" (Biasutti, 2018, p. 475).

Collaborative creative learning, as conceptualized in the papers reviewed, could be traced to sociocultural perspectives on learning (e.g., Barrett, 2006; de Bruin, 2019) where, for example, the development of our "highest mental functions" (Barrett, 2006, p. 198) and the related phenomenon of qualitative transformations in understanding emerge from systematic and sustained cooperation between students and teacher. In this way, the development of competence may be seen as a construction of new skills and knowledge through a communal process in "communities of practice" (Virkkula, 2016, p. 28; Brinck, 2017).

Within this collaborative creative learning category, studies drew upon the idea of eminence (e.g., Barrett, 2006), exploring "the ways in which the creative artist engages with the social and cultural institutions of his or her environment through the use of cultural tools and social practices developed in that environment" (Barrett, 2006, p. 198). The studies in this category were furthermore guided by theoretical ideas relating to distributed collaboration (e.g., Blom, 2012), communities of practice (e.g., Brinck, 2017) and flow (e.g., Virkkula, 2016). Accordingly, collaborative learning was conceptualized as an "emergent group property" (Blom, 2012, p. 725) that is dependent upon the nature of social relationships as pathways "toward deep engagement in learning" (de Bruin et al., 2019, p. 1). In a similar vein, Dobson and Littleton (2016, p. 334) highlight the related idea of "collaborative emergence" where actions and interactional consequences exist in a contingent relationship that may lead to unpredictable learning outcomes, and where learning processes are collaborative in the sense that each participant contributes equally.

What Are the Practical Implications of Research in Creative Collaboration or Collaborative Creativity Within Eminence Music Settings?

Overall, the 23 retained papers contributed key findings concerned with facets of musical, interpersonal and intrapersonal processes found to be associated with creative collaboration, collaborative creativity, and pedagogies of collaborative creative learning (**Table 10**). Facets of musical processes that emerged included the ideas of fusion (e.g., improvisation and composition), "pace" (i.e., a slow and evolving process occurring over time, or alternatively a rapidly paced and immediate phenomenon occurring in the moment of performance), and code systems or signifiers. Many papers highlighted the interplay between social and musical processes, positioning collaboration as a central characteristic of creative practice (e.g., Biasutti, 2015, 2018), or situating creativity as being embedded within collaboration (e.g., Kenny, 2014). Furthermore, findings from some studies pointed to the relevance of intrapersonal processes such as identity work, and the ways in which that intersected with musical and social facets of creative collaboration. Finally, a group of papers contributed to our knowledge relating to pedagogical principles and practices that frame collaborative creative learning, while similarly illustrating the key role that interpersonal issues play in mediating the relationship between collaboration and creativity.

Musical Processes

Key findings concerned with musical processes were reported in research focused on performance (e.g., Freeman and Van Troyer, 2011), composition (e.g., Hill and Fitzgerald, 2012; Hill et al., 2018), and improvisation (e.g., Blom, 2012; Virkkula, 2016; van Nort, 2018). For example, a fusion of composition and improvisation was found in the context of a laptop ensemble, where the substance of the musical improvisations was derived from a live coding process in which text messages were translated to rhythmic files and shared or further transformed over a local network (Freeman and Van Troyer, 2011). Exploring the collaborative creativity framing this process, Freeman and Van Troyer (2011) reported that the mediated improvisatory approach, involving live coding of text-based messages, fostered a slow pace and evolving process characterized by extensive use of looping and somewhat constrained risk taking.

Pace was found to be more direct and immediate when creative collaboration in an electronic music ensemble was framed by an improvisational form of conducting known as Sound-painting. Here a lexicon of gestures functioned as codes that indicated who should play what, as well as how and when it should be played. Writing about the musical process shaped by Sound-painting and mediated by machine performers as well as human performers, van Nort (2018, p. 72) explains that "in the moment" creative choices are guided by a coded system whereby "there exist a number of gestures in which continuous conductor action is directly reinforced, interpreted or reacted to by members of the ensemble." A similar quick pace of creative collaboration was reported in the context of live electronic dance music (Hill and Fitzgerald, 2012), where the musical process was characterized by "an advanced ability to listen closely and react quickly and creatively in real time in order to create a coherent

TABLE 10 | Key findings.

		Music process	Intrapersonal	Interpersonal	Pedagogy	Total
Creative collaboration	Hill and Fitzgerald (2012)	1		1		2
	Hill et al. (2018)	1		1		2
	Khodyakov (2007)	1		1		2
	Morgan et al. (2015)	1		1		2
	Tan et al. (2020)	1		1		2
	van Nort (2018)	1		1		2
	Sub-Total	6		6		12
Collaborative creativity	Biasutti (2015)	1		1		2
	Biasutti (2018)	1		1		2
	de Bruin (2019)	1		1		2
	Freeman and Van Troyer (2011)	1		1		2
	Kenny (2014)	1		1		2
	MacDonald and Wilson (2006)	1	1	1		3
	Marchini et al. (2014)	1		1		2
	Wilson and MacDonald (2012)	1	1	1		3
	Wilson and MacDonald (2017)			1		1
	Sub-Total	8	2	9		19
Collaborative creative learning	Barrett (2006)			1	1	2
	Barrett and Gromko (2007)			1	1	2
	Blom (2012)			1	1	1
	Brinck (2017)	1		1	1	3
	de Bruin (2016)			1	1	1
	de Bruin et al. (2019)			1	1	2
	Dobson and Littleton (2016)			1	1	2
	Virkkula (2016)		1	1	1	3
	Sub-Total	1	1	8	8	18
	Total key findings	15	3	23	8	49*

**This number adds to more than 23 because several papers contributed key findings in more than one category.*

groove and satisfying musical whole" (p. 170). In this instance—and contrasting with the examples where gestural or text-based codes mediated the musical collaboration—the layered rhythmic structures and sound textures formed the code system that guided and shaped the evolving creative performance.

Interplay Between Social and Musical Processes

The closely enmeshed strands of musical and interpersonal processes have been highlighted in research concerned with creative collaboration (Khodyakov, 2007; Hill and Fitzgerald, 2012; Morgan et al., 2015; Hill et al., 2018; van Nort, 2018; Tan et al., 2020) and collaborative creativity (Freeman and Van Troyer, 2011; Kenny, 2014; Marchini et al., 2014; Biasutti, 2015, 2018; de Bruin, 2019). This intersection between musical and social facets of creative collaboration was evidenced by Morgan et al. (2015), who reported a link between timing synchrony and interpersonal eye contact among improvising drummers, as well as correlations between visual contact and self-reports of creativity and engagement. The interplay between musical and social processes was also reported by Kenny (2014) who highlighted "privileging improvisation, maintaining challenge, and building knowledge through leadership and collaboration" as key mechanisms whereby creative practice (in this case in the context of jazz) may be situated in collaboration. Social bonding and unity of purpose (a function of interpersonal processes) have been reported to be integral to the musical process (Hill and Fitzgerald, 2012; Tan et al., 2020). Unity or mutual understandings relating to the interwoven strands of social and musical processes were further illustrated by Khodyakov (2007) who reported that "successful performance [in a conductorless, democratic orchestra] requires both trust and control" (p.18). Creative collaboration was achieved outside of the limitations of hierarchical structures typically found in orchestras, instead being premised upon shared creative decision-making framed by mutual obligation and expectations, civility and leadership rotation.

Subsequently, Hill et al. (2018), analyzing examples of their own collective composition work that occurred over a longitudinal (2-year) project, reported conflict to be an integral step of a process that also included instruction, cooperation and collaboration. Moments of conflict were found to be followed by sustained periods of engagement in the task, where group flow and empathetic creativity emerged. A critical issue highlighted by this study was that conflict could function as a catalyst for a creative musical process experienced within the rehearsal space, but that this occurred within a well-established, "meta-narrative" of a collaborative musical relationship evolving over time.

Biasutti (2015, 2018) investigated professional musicians engaged in collaborative online composition, noting two overarching and intersecting categories of musical and social processes. Collaboration in both of those process domains was achieved through verbal as well as non-verbal communication, and was underpinned by individual accountability, a commitment to high quality work and cooperation at all stages of experimenting, listening/evaluating, constructing, playing, and dealing with technical issues. Finally, Marchini et al. (2014) used computer modeling to explore the expressive parameters of performance, comparing solo to ensemble (string quartet) conditions. Distinctive differences were found between the two conditions, suggesting that interpersonal processes influenced the expressive nature of the performance. However, there was also some evidence that the expressivity in the solo condition was to some extent shaped by the experience of having collaborated in the ensemble condition (participants were members of a group that performed together on a regular basis); in other words, the musical implications of interpersonal processes reached beyond in the moment transactions. Collectively, these papers raise critical questions about the relationship between the individual and the collective, between tradition and unpredictability, and between the musical and social processes that characterize collaborative creativity in music.

Interpersonal and Intrapersonal Issues

Interpersonal and intrapersonal intersections have been explored in relation to the emergent and situated creative practice of jazz improvisation (MacDonald and Wilson, 2006; Wilson and MacDonald, 2012, 2017; de Bruin et al., 2019). The deeply social nature of jazz improvisation is discussed extensively in this literature, which also highlights jazz improvisation as a context where musical identity work can be shaped (e.g., Wilson and MacDonald, 2012, 2017). For example, identity work was shaped by discourses of mastery (corresponding to an incremental theory of self, whereby individuals believe in their own capacity to develop) vs. mystery (corresponding to an entity theory of self, whereby individuals are likely to believe that musical talent is a fixed trait). Furthermore, identity as a member of the jazz community was found to be reinforced by discourses that positioned improvisation as a "conversation" or alternatively as a "transcendental" creative practice founded upon flow-like experiences "of submersion of self within [the] group" (MacDonald and Wilson, 2006, p. 73). Learning to be a Jazz musician was also discussed within a long-term framework of identity development and learning (de Bruin, 2016) characterized by overlapping phases of self-regulation, co-regulation, and socially shared regulation (de Bruin et al., 2019). An overarching message in the literature is that collaborative creativity may involve balancing on the one hand exploration, diversity and unpredictability with, on the other, trust, familiarity, and convention. A further overarching message is that musical interactions have been found to be inseparable from interpersonal issues. For example, musical signifiers such as the choice to be silent or to play could be interpreted in multiple ways, requiring co-improvisers to draw on shared knowledge and experience to interpret the intention behind these signifiers (Wilson and MacDonald, 2012). At the same time, musical expectations could be confounded or disrupted by unpredictable or unexpected musical exchanges; in these instances, tensions between certainty and uncertainty required flexible responses and a tolerance–or even celebration of—ambiguity. This flexibility in turn was found to be premised upon trusting relationships and familiarity established over time (Wilson and MacDonald, 2017).

Pedagogies of Collaborative Creative Learning

Several studies have interrogated the pedagogies that characterize collaborative creative learning. Findings from these studies highlight the themes of exploration, embracing diversity, learning in community and transformation of knowledge. This body of research raises critical questions about the nature of the collective practice itself, within which collaborative creative learning can occur (Brinck, 2017). In this vein, several authors discuss situated learning in community, where students make music alongside professionals (e.g., Virkkula, 2016; Brinck, 2017; de Bruin et al., 2019). Overall, these papers point to a view of collaborative creative learning as being deeply embedded in collective, improvisational practices that embrace diversity and unpredictability (Brinck, 2017). Specific processes by which collaborative creative learning could be nurtured were concerned with the "communication of masterful standards" (Brinck, 2017, p. 221), learning how to learn, socialization (e.g., positive expectations, shaping values, and orientations to creative practice) and role acquisition (Virkkula, 2016; de Bruin et al., 2019). Pedagogical approaches took the form of scaffolded interactions such as modeling; problem-finding and guidance toward collaborative solutions. A sense of mutuality and shared regulation, expressed as joint goals, shared resources and interdependent rewards, was achieved through perspective-taking; role swapping and boundary crossing; and the use of dialogue (verbal or musical) for co-construction of knowledge and navigating resistance to change. Such practices offered "numerous possibilities for (changing) participation" for students and professionals alike (Brinck, 2017, p. 221) and—by extension—could be responsive to the diversity and unpredictability that characterized the collaborative and creative work.

Similar pedagogical and interpersonal issues were identified in the more formal contexts of collaborative creative learning among eminent composer-teachers and undergraduate student-composers (Barrett, 2006; Barrett and Gromko, 2007). Here, the communities of learning were positioned as "thought communities" (Barrett and Gromko, 2007, p. 214) distinguished by joint effort and social support, yet also framed by disciplinary historical, cultural and social practices. Pedagogical approaches were non-linear and reciprocal and could be conceptualized on a continuum from cooperative to autonomous. For example, at the cooperative end of this continuum were instances of scaffolding whereby the teachers provoked students to describe and explain or used probing and questioning to guide students toward solutions. In contrast, autonomous pedagogical approaches occurred when teachers became "fellow travelers," seeking unpredictable solutions, extending the boundaries of tradition, and creating an environment in which could be found "license to change" (Barrett, 2006, p. 202).

Finally, key findings relating to pedagogies of collaborative creative *peer* learning have been reported (e.g., Blom, 2012; Dobson and Littleton, 2016). Where Blom (2012) focused on interdisciplinary peer learning temporally and geographically located within a specific workshop context, Dobson and Littleton (2016) explored disciplinary-specific (digital composition) peer learning processes that occurred over time and within multiple private and social spaces. Notwithstanding these contextual differences, both papers illustrate the phenomenon of "disruption" that was noted in the papers concerned with jazz improvisation (e.g., Wilson and MacDonald, 2017) and the role that can play in creative learning. For example, Dobson and Littleton (2016) highlight that collaboration has the capacity to disrupt or confound familiar digital practices, potentially meeting resistance to change but also prompting "possibility thinking" whereby students consider questions of "what if ..." and develop elaborate understandings of steps to take and potential outcomes. In a similar vein, Blom (2012) noted resistance to change when music students encountered collaborative and improvisatory practices that disrupted their familiar and more individualistic artistic approaches. Noting that music students were initially reticent in collaboration with peers from other arts disciplines, Blom also highlighted the possibilities of knowledge that emerged from the musicians' proximity to—and interactions with—their drama and dance peers for whom tensions between individuality and collaboration were comparatively less prominent. Both papers also indicate that peer learning in creative work involves using dialogue or artistic practice to develop a common knowledge about each other's preferences, experiences and anticipated outcomes. This dynamic and continually evolving knowledge base becomes the basis for generating, evaluating and negotiating ideas within a process that may fluctuate between being "homogeneous"—where each voice is equal—and "heterogeneous," where a leader is acknowledged (Blom, 2012, p. 734).

DISCUSSION AND CONCLUDING REMARKS

The findings presented above illustrate that eminence investigations of creative collaboration and collaborative creativity have been undertaken within a range of settings in higher education, professional development and professional music-making with a more limited focus on these concepts within research carried out in community music settings. Studies have been carried out in contexts representing a small range of musical genres, with the majority focussing on creative collaboration in jazz or popular music. Studies carried out within Western classical music contexts have focused primarily on improvisation or composition. Very little research has been undertaken outside of jazz, composition, contemporary electronic or digital music genres, or indeed Western musical contexts. Further research is needed to interrogate the relevance of conceptions of creative collaboration and collaborative creativity as presented in these papers across diverse cultural contexts and across multiple musical genres.

The majority of studies have been designed within a qualitative exploratory paradigm, primarily case study, and seek to interrogate interpersonal processes and behaviors, musical interactions and the use of language to construct shared understandings around the nature of collaboration and creativity in improvisation, composition and contemporary practices in electronic music. A range of methods have been used, with the most prominent methods being semi-structured interviews, observations and participant observation. Analyses of qualitative data were framed in a range of different ways, including thematic analysis, discourse analysis, content analysis, IPA and the constant comparative method. Whilst many studies employed more than one method, only three studies used quantitative approaches. We suggest that there is opportunity to develop more diverse research methods that move beyond the identification of individual elements of creative collaboration and collaborative creativity in order to understand the potential causes and effects of these phenomena. Further methodological diversity might also be explored through the use of practice-based and/or practice-led artistic research.

The phenomena of interest ranged across expected categories of creative collaboration and collaborative creativity, as these were the focus of the review. An emergent category was that of collaborative creative learning, reflected in the higher education (8) and professional development (5) settings in which the bulk of the studies were located. Those studies investigating collaborative creative learning focused largely on strategies for scaffolding new knowledge in situated learning settings casting the teacher variously as collaborator, guide, coach, mentor. Further research is needed to understand the relationships between the positioning of these roles and the levels of experience, skills and expertise manifest in the teaching-learning interaction. Further investigation is also warranted in understanding the ways in which peer-to-peer learning is facilitated in creative collaboration and collaborative creative music learning settings.

Emergent inter and intra-personal issues highlighted the elements of disruption, conflict, and pace as components of creative collaboration and collaborative creativity, suggesting that these are perhaps necessary intersecting points in the development of collaborative work. The identification of these elements returns us to John-Steiner's four patterns of creative collaboration: distributed, complementary, family, and, integrative. None of the studies included in this systematic literature review could be classified as a family collaboration in terms of a familial connection as described by John-Steiner. A small number of those studies undertaken in professional settings (e.g., Khodyakov, 2007; Hill and Fitzgerald, 2012) might be classified as complementary in that musical goals were realized through drawing on complementary expertise, discipline knowledge, roles and temperaments. The studies were largely tacet in acknowledging distributed creativity in both John-Steiner's sense of drawing on loose networks of collaborative groups, or Glaveanu's notion of interactions between creator, audiences, materials, embodied actions, and the historico-socio-cultural affordances of the creative activities, although these might be inferred. Implicit in a number of studies is the underlying importance of relationships across time, of familiarity, of shared experience, of habitual patterns of work, and shared knowledge and experience that functions in a tacet way as a unifier (socially and aesthetically). It is also salient to note that John-Steiner's work emerged from a feminist paradigm, exploring theories of relational dynamics and gendered issues of ownership. Of the 23 studies investigated here, 14 reported gender with 10 providing data from female participants. In these studies, female participation was less than half that of males (32:72). Further research is warranted to investigate the patterns and forms of male and female processes of creative collaboration, collaborative creativity, and collaborative creative learning.

Through this systematic literature review of creative collaboration and collaborative creativity in the music laboratories of performance, improvisation and composition we have sought to interrogate the ways in which these concepts have been theorized and implemented. Whilst collaboration might be a long-standing practice in music (Delalande, 2016) it has a much shorter history as a research phenomenon and holds great potential for further investigation.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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REFERENCES

Amabile, T. (1983). *The Social Psychology of Creativity*. New York, NY: Springer Verlag.

Barrett, M. (2006). "Creative collaboration": an "eminence" study of teaching and learning in music composition. *Psychol. Music* 34, 195–218. doi: 10.1177/0305735606061852

Barrett, M. S., Ford, A., Murphy, P., Pollett, P., Sellars, E., and Viney, L. (2014). "The scattering of light: shared insights into the collaborative and creative processes that underpin the development and performance of a commissioned work," in *Collaborative Creative Thought and Practice in Music*, ed M. S. Barrett (Surrey: Ashgate Publishing limited), 17–31.

Barrett, M. S., and Gromko, J. E. (2007). Provoking the muse: a case study of teaching and learning in music composition. *Psychol. Music* 35, 213–230. doi: 10.1177/0305735607070305

Bayley, A., and Lizée, N. (2016). Creativity layers and continuities: a case study of Nicole Lizée and the Kronos Quartet. *Music. Sci.* 20, 393–412. doi: 10.1177/1029864916631917

Becker, H. (1982). *Art Worlds*. Berkeley: University of California Press.

Biasutti, M. (2015). Creativity in virtual spaces: communication modes employed during collaborative online music composition. *Think. Skills Creat.* 17, 117–129. doi: 10.1016/j.tsc.2015.06.002

Biasutti, M. (2018). Strategies adopted during collaborative online music composition. *Int. J. Music Educ.* 36, 473–490. doi: 10.1177/0255761417741520

Blom, D. (2012). Inside the collaborative inter-arts improvisatory process: tertiary music students' perspectives. *Psychol. Music* 40, 720–737. doi: 10.1177/0305735611401127

Brinck, L. (2017). Jamming and learning: analysing changing collective practice of changing participation. *Music Educ. Res.* 19, 214–225. doi: 10.1080/14613808.2016.1257592

Bruner, J. S. (1996). *The Culture of Education*. Cambridge, CA: Harvard University Press.

Cole, M. (1996). *Cultural Psychology: A Once and Future Discipline*. Cambridge, MA: Belknap Press of Harvard University Press.

Cooke, A., Smith, D., and Booth, A. (2012). Beyond PICO: the SPIDER tool for qualitative evidence synthesis. *Qual. Health Res.* 22, 1435–1443. doi: 10.1177/1049732312452938

Csikszentmihalyi, M. (1996). *Creativity*. New York, NY: Basic Books.

de Bruin, L. R. (2016). Journeys in jazz education: learning, collaboration, and dialogue in communities of musical practice. *Int. J. Community Music* 9, 307–325. doi: 10.1386/ijcm.9.3.307_1

de Bruin, L. R. (2019). Improvising musicians' self-regulation and distributed creativities: a phenomenological investigation. *Think. Skills Creat.* 32, 30–41. doi: 10.1016/j.tsc.2019.03.004

de Bruin, L. R., Williamson, P., and Wilson, E. (2019). Apprenticing the jazz performer through ensemble collaboration: a qualitative enquiry. *Int. J. Music Educ.* 38, 208–225. doi: 10.1177/0255761419887209

Delalande, F. (2016). Postscript: music composition, creativity, and collaboration–an old story, only recently told. *Music Sci.* 20, 457–461. doi: 10.1177/1029864916646719

Dobson, E., and Littleton, K. (2016). Digital technologies and the mediation of undergraduate students' collaborative music compositional practices. *Learn. Media Technol.* 41, 330–350. doi: 10.1080/17439884.2015.1047850

Ericsson, K. A. (2014). Why expert performance is special and cannot be extrapolated from studies of performance in the general population: a response to criticisms. *Intelligence* 45, 81–103. doi: 10.1016/j.intell.2013.12.001

Freeman, J., and Godfrey, M. (2010). Creative collaboration between audiences and musicians in *Flock*. *Digit. Creat.* 21, 85–99. doi: 10.1080/14626261003786244

Freeman, J., and Van Troyer, A. (2011). Collaborative textual improvisation in a laptop ensemble. *Comput. Music J.* 35, 8–21. doi: 10.1162/COMJ_a_00053

Gardner, H. (1993). *Creating Minds: An Anatomy of Creativity Seen Through the Lives of Freud, Einstein, Picasso, Stravinskym Elior, Graham, and Gandhi*. New York, NY: Basic Books.

Glaveanu, V. P. (2010a). Paradigms in the study of creativity: introducing the perspective of cultural psychology. *New Ideas Psychol.* 28, 79–93. doi: 10.1016/j.newideapsych.2009.07.007

Glaveanu, V. P. (2010b). Principles for a cultural psychology of creativity. *Cult. Psychol.* 16, 147–163. doi: 10.1177/1354067X10361394

Glaveanu, V. P. (2014). *Distributed Creativity: Thinking Outside the Box of the Creative Individua*l. Cham: Springer.

Glaveanu, V. P., Gillespie, A., and Valsiner, J. (eds.). (2014). *Rethinking Creativity: Contributions From Social and Cultural Psychology*. Hove/New York, NY: Routledge.

Hill, B., and Fitzgerald, J. (2012). Human machine music: an analysis of creative practices among Australian live electronica musicians. *Perfect Beat* 13, 161–180. doi: 10.1558/prbt.v13i2.161

Hill, M., Hill, B., and Walsh, R. (2018). Conflict in collaborative musical composition: a case study. *Psychol. Music* 46, 192–207. doi: 10.1177/0305735617704712

Joanna Briggs Insitute (2017). *Checklist for qualitative research. The Joanna Briggs Institute critical appraoisal tools for use in JBI systematic reviews*. Available online at: www.joannabriggs.org (accessed July 3, 2021).

John-Steiner, V. (2000). *Creative Collaboration*. New York, NY: Oxford University Press.

Kenny, A. (2014). Collaborative creativity within a jazz ensemble as a musical and social practice. *Think. Skills Creat.* 13, 1–8. doi: 10.1016/j.tsc.2014.02.002

Khodyakov, D. M. (2007). The complexity of trust-control relationships in creative organizations: insights from a qualitative analysis of a conductorless orchestra. *Soc. Forces* 86, 1–22. doi: 10.1353/sof.2007.0100

Lincoln, Y., and Guba, E. (1985). *Naturalistic Inquiry*. Beverley Hills, CA: Sage Publications.

MacDonald, R., Miell, D., and Wilson, G. (2005). "Talking about music: a vehicle for identity development," in *Musical Communication*, eds D. Miell, R. MacDonald, and D. Hargreaves (Oxford: Oxford University Press), 321–338.

MacDonald, R. A. R., and Wilson, G. B. (2006). Constructions of jazz: how jazz musicians present their collaborative musical practice. *Music. Sci.* 10, 59–83. doi: 10.1177/102986490601000104

Marchini, M., Ramirez, R., Papiotis, P., and Maestre, E. (2014). The sense of ensemble: a machine learning approach to expressive performance modelling in string quartets. *J. New Music Res.* 43, 303–317. doi: 10.1080/09298215.2014.922999

Miell, D., and Littleton, K. (2004). *Collaborative Creativity*. London: Free Association Books.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., and PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* (2009) 6:e1000097. doi: 10.1371/journal.pmed.1000097

Morgan, E., Gunes, H., and Bryan-Kinns, N. (2015). Using affective and behavioural sensors to explore aspects of collaborative music making. *Int. J. Hum. Comput. Stud.* 82, 31–47. doi: 10.1016/j.ijhcs.2015.05.002

Mumford, M. D. (ed.). (2012). *Handbook of Organizational Creativity*. Dan Diego, CA: Academic Press.

Paulus, P. B., and Nijstad, B. A. (eds.). (2019). *The Oxford Handbook of Group Creativity and Innovation*. New York, NY: Oxford University Press.

Ravet, P. (2016). Negotiated authority, shared creativity: cooperation models among conductors and performers. *Music. Sci.* 20, 287–303. doi: 10.1177/1029864915617232

Sawyer, R. K. (2017). *Group Genius: The Creative Power of Collaboration (Revised Edition)*. New York, NY: Basic Books.

Seddon, F. A. (2005). Modes of communication during jazz improvisation. *Br. J. Music Educ.* 22, 47–61. doi: 10.1017/S0265051704005984

Tan, L., Tjoeng, J., and Sin, H. X. (2020). "Ngeli": flowing together in a Gamelan ensemble. *Psychol. Music* 49, 804–816. doi: 10.1177/0305735620909482

van Nort, D. (2018). Conducting the in-between: improvisation and intersubjective engagement in soundpainted electro-acoustic ensemble performance. *Digit. Creat.* 29, 68–81. doi: 10.1080/14626268.2018.1423997

Virkkula, E. (2016). Communities of practice in the conservatory: learning with a professional musician. *Br. J. Music Educ.* 33, 27–42. doi: 10.1017/S026505171500011X

Vygotsky, L. (1978). *Mind in Society: The Development of Higher Psychological Processes (A. Kozulin, Trans.)*. Cambridge, MA: Harvard University Press.

Vygotsky, L. (1986). *Thought and Language (A. Kozulin, Trans.)*. Cambridge, MA: MIT Press.

Wilson, G. B., and MacDonald, R. A. R. (2012). The sign of silence: negotiating musical identities in an improvising ensemble. *Psychol. Music* 40, 558–573. doi: 10.1177/0305735612449506

Wilson, G. B., and MacDonald, R. A. R. (2017). The construction of meaning within free improvising groups: a qualitative psychological investigation. *Psychol. Aesthet. Creat. Arts* 11, 136–146. doi: 10.1037/aca0000075

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