MADNESS AND CREATIVITY: YES, NO OR MAYBE?

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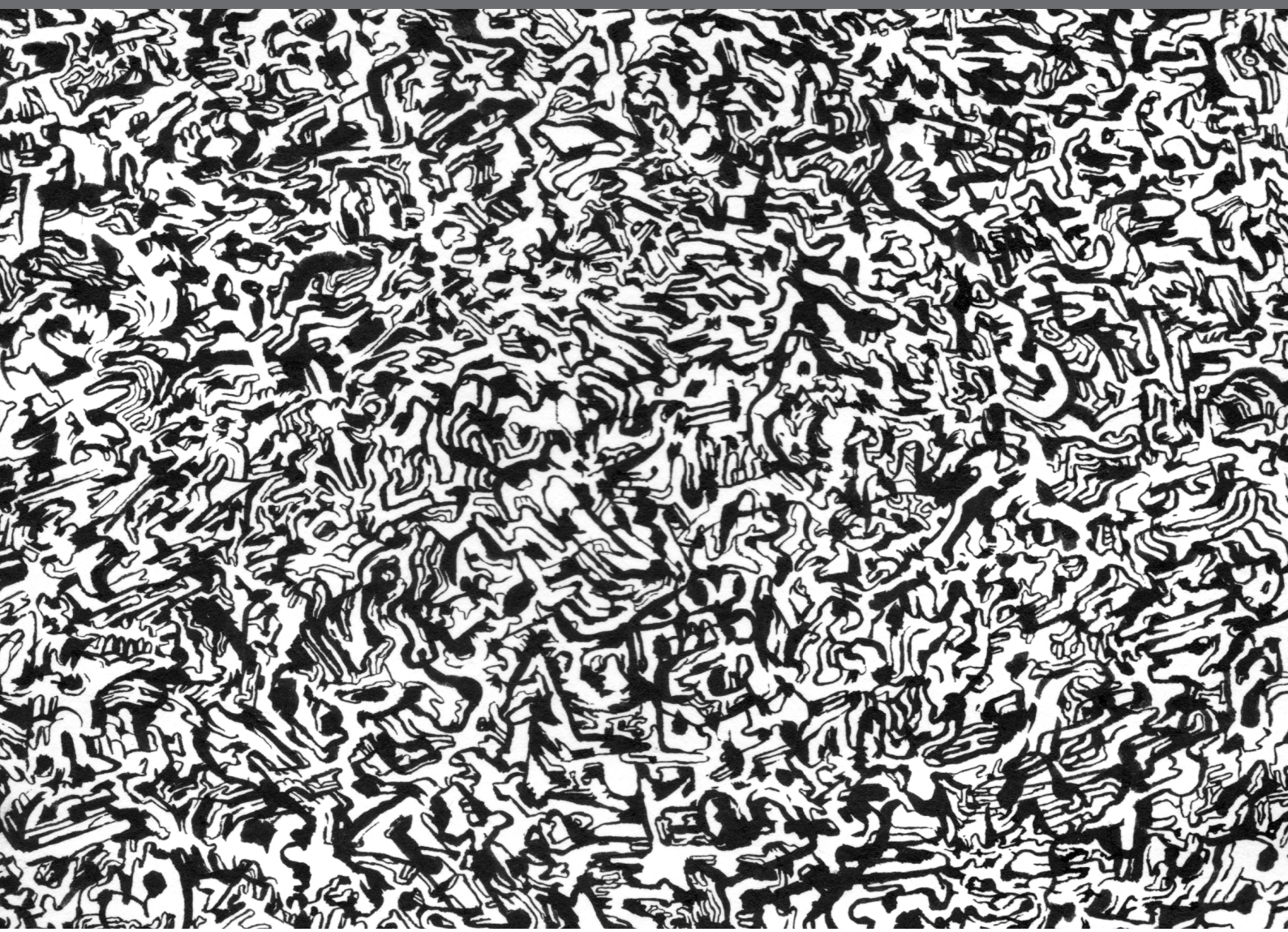

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MADNESS AND CREATIVITY: YES, NO OR MAYBE?

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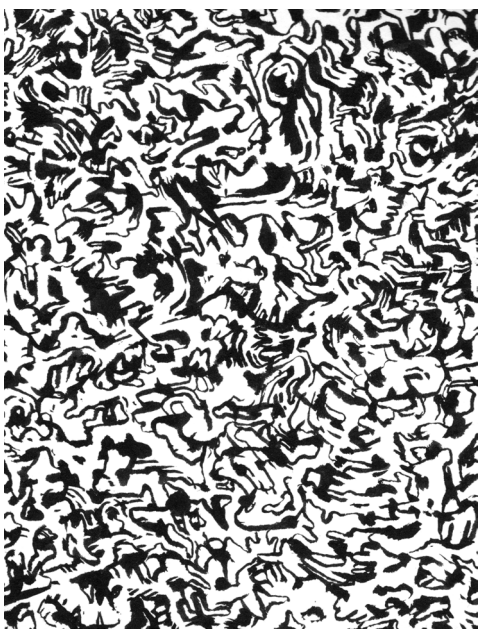

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The pervasive idea that madness and creativity are intricately linked is one that holds tremendous fascination for both scientists and the general public alike. Although this view was at first largely driven by anecdotal evidence showcasing the manifestation of mental illness in individuals who exhibited extraordinary levels of creativity in various spheres of life, it initiated a strong impetus to empirically investigate the association between mental health and creativity.

A variety of approaches (and combinations of approaches) have been adopted to address this association including clinical, personality, psychometric, behavioral, cognitive, historiometric and neuroscientific. Despite the ever accumulating body of evidence over the past six decades investigating this link, what is lacking is a comprehensive overview of the disparate findings from these different approaches that will enable us to address the question of whether there is an empirically founded relationship between creativity and mental illness. And if such a link does exist, what is the nature of this association?

The purpose of this Research Topic was to motivate theorists and researchers to answer this question (or at least attempt to do so) given the available evidence thus far. The themes of interest that were open to exploration in view of this topic included:

(a) Which mental disorders are positively associated with creativity?
(b) Which mental disorders are negatively associated with creativity?

(c) The dynamics of information processing biases (positive versus negative) associated with psychiatric and high-risk populations
(d) Theories regarding the madness-creativity link
(e) Personality-based studies on creativity
(f) Creativity, mental illness and the brain
(g) Genes and creativity
(h) How can studies on neurological populations inform this debate?
(i) What are the areas of impact with regard to real world applications and practice?
(j) Historical timeline of this question
(k) Evolutionary perspectives on the madness-creativity link
(l) Methodological problems associated with this field
(m) Philosophical issues to bear in mind when investigating this domain
(n) The usefulness of the "troubled genius" concept

The invitation to contribute was open to all interested academics regardless of whether they were seasoned explorers within this field of study or just beginning to get their feet wet in its murky waters. As a result of adopting this inclusive approach, the contributions showcase a wide variety of perspectives from academic departments and institutions the world over. What is most encouraging is that so many were willing to openly take on the challenge of tackling this difficult question head on. We hope future discussions that follow through as a result of this collective effort will prove to be just as fruitful.

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EDITORIAL
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Editorial: Madness and creativity—yes, no or maybe?

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Keywords: psychopathology, creative thinking, divergent thinking, mental illness, psychosis, psychosis proneness, creative cognition

There is something inherently appealing about the idea that creativity and psychopathology are inextricably linked. The eagerness with which this idea is perpetuated and often exaggerated was evidenced most recently in the media frenzy following the publication of a genome-wide association study which demonstrated what in effect was a modest genetic association between creativity and psychosis (Power et al., 2015).

For most investigators of the madness-creativity nexus, the question is not really answered with the categorical and binary choice of whether or not there is an association. Advocates of the "No" camp answer in the negative because they are unconvinced by the quantity and/or quality of evidence provided to support the connection. The same evidence is gauged by "Yes" advocates as constituting enough proof for the claim. It is only by venturing below the surface to understand the actual nature of the association that one can see why this is such a divisive issue. A variety of questions emerge. What is the strength and shape of this association? Is the relation mechanistic? Does one emerge as an epiphenomenon of the other? Is the similarity merely superficial? Is this a question worth asking? Are we asking the wrong question?

The purpose of this Research Topic was to motivate theorists and researchers in the field to take a stance in answering this question given the available evidence thus far (Kaufman, 2014). It is very telling that none of the 14 contributions advocated a resounding "Yes" verdict. The reason for this is straightforward. It is patently clear that the evidence to make a strong claim in the affirmative (all highly creative people have some form of mental illness; all people who have some form of mental illness are highly creative) simply does not exist. So any arguments of deductive reasoning that follow from either of these false premises would be invalid.

The "No" camp has one flag-bearer who, on the basis of grounds such as paucity of empirical evidence, selective data reporting, heterogeneity in types of mental illness, and heuristics-based reasoning behind the link, asserts not only that there is no positive relationship between creativity and mental illness, but that the relationship is in fact negative (Dietrich, 2014). From this standpoint, it is good mental health that leads to more creativity as the need to be creative is part of the self-actualization drive that sits atop the hierarchy of needs pyramid (Maslow, 1943).

In not taking a clear side on the debate, the "Maybe" (or "Yes, but") camp provides a rich variety of perspectives that seek to uncover the dynamics of the relation between creativity and psychopathology. Some provide methods-based grounds for why the association can be both positive and negative. One commentary addresses the issue of sampling which, as the cross-sectional distribution of creative productivity is highly skewed, gives rise to divergent findings depending on which part of the distribution is being sampled (Simonton, 2014). Another focuses on the metric of information processing biases which are held to orchestrate the connection between creativity and psychopathology (Abraham, 2014). As this relationship follows an inverted-U as opposed to a linear function, it can result in evidence for associations in either direction. A case in point on how evidence of the creativity-psychopathology link is necessarily tied to the

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type of creativity measure being employed as well as to various forms of psychopathology is showcased in one of the original research articles (Zabelina et al., 2014). That a coherent picture can only be drawn with the explicit consideration and unambiguous acknowledgment of the nature of the construct under study, in terms of definition, operationalization, measures of assessment and populations sampled to assess the association, was highlighted in one of the opinion articles (Fisher, 2015).

Drawing from evolutionary mechanisms that are held to underlie the core components of creativity: novelty (through generators of variation) and usefulness (through generators of fit selection), one postulation is that psychopathology may stem from the extreme ends of these operating principles—psychosis in the case of novelty and autism in the case of usefulness (Jung, 2014). The need to distinguish between different types of psychopathology in relation to creativity, especially in light of the potentially contradictory findings that often result, is captured effectively in one of the original research articles, where creative performance was positively correlated with the analytical/systemizing facets of autistic spectrum characteristics and negatively correlated with the social/empathizing elements of the same (Takeuchi et al., 2014). Others have emphasized that any resemblance in the performance of highly creative people with certain forms of psychopathology is limited to novelty generation as, unlike in the case of psychopathology, highly creative individuals exert efficient control in evaluating the appropriateness of their ideational output (Fink et al., 2014).

Some perspectives showcase brain-based approaches in verifying the link between creativity and psychopathology. Relatively global differences in terms of brain organization, such as via hemispheric asymmetry, are among the earliest ideas that have been put forward to characterize the association (Lindell, 2014). The alternative approach is to focus on specific brain regions and networks. Given the predominant role played by the prefrontal cortex in orchestrating virtually all facets of higher-order function, one means of assessing mechanisms of creative cognition is in terms of prefrontal function and dysfunction. The evidence paradoxically indicates that both enhanced and diminished creative function can result from damage to different parts of this brain structure when evaluating spontaneous versus controlled aspects of the creative process (de Souza et al., 2014). One network-based hypothesis holds that the creativity-psychopathology link is an epiphenomenon that results when the neurocognitive tradeoff between rule-based/top-down systems (prefrontal) and data-driven/bottom-up systems (sensorimotor) is compromised (Ramey and Chrysikou, 2014). This vulnerability often leads to an increase in output quantity (fluency), which in turn gives rise to an increased likelihood of output quality (novelty/uniqueness). An alternate conceptualization of balance between two regulatory systems as mediating the creativity-psychopathology link is that of stability versus flexibility in neural network dynamics, specifically in relation to dopamine and response entropy (Bilder and Knudsen, 2014).

Clinically-based perspectives turn the tide of this dialogue on its head by exploring the alternate possibility that undergoing psychopathological states is what motivates afflicted individuals to seek creative avenues in order to improve their psychological health and well-being (Forgeard and Elstein, 2014). A vital insight of this perspective is that the drive may not be to increase creative output *per se* but to enhance crucial competencies such as flexibility and self-efficacy, which are related but not analogous to creativity. Other accounts focus on the need to consider that the presence of specific personality traits which often accompany psychopathological states, such as openness to experience, may serve as protective factors by channeling the chaotic drive for novelty generation in a productive manner (Kaufman and Paul, 2014).

In bringing these different perspectives together in one common forum, the hope is that this collective effort at addressing this intriguing question will lead to further constructive dialogue and debate in the scientific arena by adding more substance and rigor to discussions of the association between creativity and psychopathology.

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OPINION ARTICLE
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The mythconception of the mad genius

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Take troubled Vincent van Gogh, famed 19th century painter who suffered from bipolar disorder, cut off part of his left ear, and eventually committed suicide. Or Isaac Newton, eccentric 17th century physicist, general headcase, and judging from his leviathan superego, a candidate for making the diagnostic criteria of at least half a dozen psychological disorders. No sooner do we contemplate this aberrant pair, a whole army of mad geniuses springs to mind led by such illustrious figures as autistic Wolfgang Amadeus, depressed Ludwig van, or tortured Edgar Allan. Like Franz Kafka, Robert Schumann, Michelangelo, Virginia Wolf, Richard Strauss, John Nash, or Ernest Hemingway, they were all, at some point in their lives, anguished, tormented, alcoholic, angst-ridden, manic, outright psychotic, or just plain weird. Add the mind-boggling savant syndrome, throw in a quote from a venerable ancient Greek for good measure—say, Aristotle: "No great mind has ever existed without a touch of madness"—and we have the making of mythconception (for more details, see Rothenberg, 1990; Schlesinger, 2009, 2012; Simonton, in press).

Writers must by now have spilled gallons of ink over the purported link between creativity and madness filling shelves of books and articles (e.g., Post, 1994; Kaufman, 2005; Koh, 2006). Such tales from the insanity zone are nuggets of pure gold for the true believer in the unlock-your-infinite-creative-potential movement. What if we could just open "the doors of perception?" What would we have lost had Prozac turned Nietzsche into a regular bloke? Sadly, there is no sign that this kettle is going off the boil anytime soon. Hollywood can't get enough of it. Nor does the TED Conference, the new home of international meme laundering. The narrative of the troubled genius just strikes all the right chords for coverage in the tweet-sized attention span of modern news reporting. Not even the BBC can resist, having featured a headline last year reading: "Creativity 'closely entwined with mental illness"' (Kyaga et al., 2011; Roberts, 2012). Such frenzied enthusiasm and a few flag-waving generalization might be forgiven among those untouched by the purifying powers of statistical reasoning, but one would expect more professional scrutiny in the rarefied air of peer-reviewed psychology journals. Far from it. Even in the academic ether do respectable people, even those of the highest scientific standing, regularly rise to levels of speculation that can safely be called imprudent (see, for instance, Jamison, 1993).

So what, then, is the link? Is there indeed just a thin line separating insanity from genius? The best place to start looking for an answer, one would think, is the scientific literature—if that is the right phrase to use here. I say this because one quickly discovers, while perusing this literature, that there does not seem to be any scientific data on the matter. The entire thesis of the highly-gifted mentally ill rests entirely on an unholy marriage of case reports and anecdotal storytelling (see for instance, Jamison, 1993 or Post, 1994). It is not uncommon, for instance, to read articles galloping through so many esoteric live episodes, irrelevant factoids, and so much delicious gossip (did you know that the reclusive William Cavendish insisted on having a chicken roasting at all hours of the day?), that the validity of the link is all but a foregone conclusion. But it is one thing to be enchanted by folklore, it is quite another to turn a blind eye to lethal doses of selective data reporting.

Like no other field of psychology, the study of creativity is beset with nebulous concepts, combustible propositions and myopic theorizing, to say nothing of all the vacuous fluff out there. The fog enshrouding this particular Potemkin village is nevertheless easy to lift. We need only to drill into some basic numbers on mental illness that continue to be enthusiastically ignored—incidence and prevalence data, to be precise—take the wraps off an astonishing medley of cognitive biases—base rate fallacy, availability heuristic, illusionary correlations and the like—and unpack a few question-begging definitions of creativity.

As every undergraduate student knows, to establish a positive correlation between event A and some other event B, you need to collect baseline data on the frequency of both events. According to the (World Health Organization, 2013), mental illness, unlike genius, is by no means a rare phenomenon. Mood disorders, such as the various forms of bipolar and depressive disorders, occur in about 10% of the population. This amounts to hundreds of millions of people! Similar prevalence rates exist for anxiety disorders, which makes for a few more—wait for it—hundreds of millions of people! There is somewhat less suffering from schizophrenia, substance abuse disorder, the different kinds of personality disorders and autism, but enough to add several tens of millions more. The Centers for Disease Control and Prevention (2001) estimated in 2001—when the world's population

stood at 6.2 billion, or about a billion less than today—that there were some 450,000,000 people living in poor mental health. The lifetime incidence of people making at least a single visit to the mind's Pre-Hell is said to be significantly over 50%.

What do these staggering numbers mean? In the somber land of regression curves, they tell us that we can spare ourselves the trouble of determining the frequency of eminence in the population. For, irrespective of how we define creativity, let alone genius, this number must be less—vastly less. The simple truth of the matter is that the VAST majority of creative people are not mentally ill and, more importantly, the VAST majority of those suffering from psychopathology are not geniuses. Seen in this light, the claim that creativity and insanity somehow go together sounds more like densely ignorant nonsense, the stunted idea of someone who spent too many hours in a hot tub.

It isn't my goal here to make a case for the opposite claim, but, by all evidence, it is hard to escape that conclusion. By the looks of these numbers, I would wager good money that the link between mental illness and genius is negative. To be exact: extremely negative. This isn't to say that there might be something to it, perhaps if the data is parsed differently (see Simonton, in press), but this link, unqualified as in the BBC headline above, is wrong—outright! This would seems to hold not only for psychopathology *tout court*, but also for each psychological disorder alone, as well as, to restrict things further to severe cases of a given disorder or to specific types of creativity (Waddell, 1998). That this fact has been almost universally overlooked, like one would a tic, is as crazy as it is amazing.

Most psychology undergraduate students, if they are reasonably attentive, would recognize the mad-genius howler as a textbook case of the base rate fallacy (Kahneman and Tversky, 1973). This common statistical sin, also known as base rate neglect, concerns the tendency to focus on specific information and ignore generic, baseline information, even when—and here is the rub—the latter is presented. Thus, people greatly underestimate the probability of a genius being totally sane and greatly overestimate the probability of an individual with mental illness being creative. The fact is that a very large proportion of creative people have no pathological symptoms (Simonton, 2005, in press). Incidentally, the same reference point neglect occurs for insanity and violence (Stuart, 2003). This link, too, is strongly negative, despite the perception we get from the media.

But it doesn't end there. This error in thinking is so extensive and the opportunities for flummoxing so abundant that this matter is sure to continue to generate more heat than light. It is a disarming reflection of our reluctance, or inability, to think statistically that we just can't seem to snap, crackle, pop out of it. What makes our intuition misfire by such a wide margin? Seeing the world through our own warped force field is standard operating procedure of course. Psychologists have long accepted the sobering fact that our mind comes with a whole stack of cognitive biases preloaded and preinstalled. Without getting too technical about it, the one doing most of the dopamine squirting here bears the inauspiciously label "availability heuristic." It is a mental shortcut that estimates the likelihood or frequency of an event by the ease with which a specific instance of it comes to mind. So when you think about the creativity-madness link, the odd behaviors of Michael Jackson are more likely to guide you than the 99% media-invisible normals.

The availability heuristic as a cognitive mechanism was first proposed and demonstrated by Kahneman and Tversky (1973). In a now classic experiment, they asked people to judge the likelihoods of an English word either starting with the letter K or having a K as its third letter. With people more readily thinking of kitchen, kennel or kickboxing than ankle, Eskimo or acknowledge, their participants overestimated the number of words starting with a K and underestimated those with a K in third position. An English text, however, has about three times as many words with a third-place K; they are just not as available in memory.

What's more, the availability heuristic also causes illusionary correlations, for the same reason. This leads to the perception of a non-existent relationship between two events simply because they occurred together at some point in the past (Chapman, 1967). Alternatively, this false impression can also arise from the way people incorrectly integrate contingency information (Perales and Shanks, 2007). Naturally enough, the more vivid the pairing, the more people tend to enduringly conflate the events and overestimate the frequency of their co-occurrence, and thus their causal relationship. The loopy logic then comes full circle with the confirmation bias, the tendency people have of confirming their existing beliefs. Cases that substantiate the belief, and ambiguous information that can be tweaked that way, strengthens the imaginary connection, while cases that violate or disconfirm it are ignored. Consider this rather typical finding from Redelmeier and Tversky (1996), who asked arthritis patients to track the weather over 15 months and judge to what extent their condition was related to it. While the correlation was actually zero, virtually all were certain that their level of pain depended on the weather. We have here a knockdown one-two punch then. The availability heuristic serves as the seed for the illusionary correlation between madness and genius, and the confirmation bias supplies the fertilizer that nourishes it.

I could go on and on. In fact, I think I will. Pulling conceptual rabbits out of metaphysical thin air is routine business in creativity research. Open any source, academic or otherwise, and you will find the concept of creativity linked to, say, low arousal, defocused attention, right brains, unconscious processes, lateral thinking, or altered states of consciousness, to name but a few popular themes, when common sense alone tells you that their opposites are also sources of creative thinking (Dietrich, 2007). Consider, for instance, a study by Kyaga and colleagues (2011) that searched the database of Swedish registries for the insanely gifted, as it were. The real humdinger of the study was the operational definition of creativity. They found mental illness to be more common in people holding "creative occupations"—artists, writers, and scientists—compared to the evidently insipid army of accountants and auditors. Not only would this be news to engineers in Silicon Valley, but also the authors ask us to accept that writers and graphic designers are—by definitional fiat—creative. This is nuts. For the record,

this study is the one that led to the BBC headline quoted earlier.

All of this would seem to suggest that some serious scientific work needs to be done on the matter. In addition to controlling for cognitive biases, measurement and analytic issues can also contribute to a false assessment of the creativity-madness link (Simonton, in press). Until such time, I take my inspiration form the humanistic perspective and prefer to think, just like Abraham Maslow and Carl Rogers did, that creativity is associated with mental health. Standing tall at the top of the hierarchy of needs, creative imagination and expression is the hallmark of a well-adjusted, self-actualizing, fully functioning person.

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GENERAL COMMENTARY
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Can creative productivity be *both* positively *and* negatively correlated with psychopathology? Yes!

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Empirical research on the hypothesized relation between creativity and psychopathology must take care to frame the question very carefully. If a person's creativity is defined by the output of creative products, then the empirical association can be either positive or negative, depending on how that association is specified. On the one hand, individuals who make at least one creative contribution to a domain may exhibit lower risk of psychopathology than those who never do. On the other hand, among those individuals who contribute one or more creative products, those who contribute the most creative products may have higher risk of psychopathology than those who contribute the fewest creative products. These two hypotheses can both be empirically confirmed because the cross-sectional distribution of creative output is described by a highly skewed inverse power function known as Lotka's Law (Lotka, 1926). That is, the number of individuals producing n creative products is proportional to $1/n^2$ (Egghe, 2005). Given this skewed distribution, the risk rate can easily increase as a linear function of creative productivity even though the overall risk rate is strikingly lower than in the general population.

To illustrate, suppose that the following Lotka function holds for a particular creative domain: $f(n) = 100/n^2$. Then the lowest creative output is 1 and the highest 10. Let us also assume that the risk of some psychopathology increases as a positive linear function of n. In particular, we might specify the risk as $R(n) = -0.100 + 0.100^*n$. According to this hypothesized function, the risk increases from $R(1) = 0$, for the lowest level of creative output, to $R(10) = 0.90$, for the highest level of creative output. It follows from the cross-sectional distribution that (a) nearly two-thirds (i.e., about 65%) will have zero risk of psychopathology and (b) the average risk for all individuals contributing one or more creative products is only 0.09 (or 9%). The latter figure is not only one tenth of the risk hypothesized for the most prolific creator, but also presumably noticeably smaller than would likely hold in the population of individuals who made no creative contributions to a domain. For instance, it might hold that $R(0) = 0.46$ (based on Kessler et al., 2005), a figure fivefold higher.

This treatment can be generalized beyond this specific illustration. Whenever $R(1) << R(0)$, that is, the risk rate is much lower among the one-hit creative individuals, then it would still be possible to have $R(n)$ increase with increases in creative productivity n. This increase does not even have to be linear, for a positive monotonic relation will have the same effect, yielding the inequalities $R(1) < R(2) < R(3) < \ldots R(n-1) < R(n)$. In fact, the creativity-psychopathology relation in the literary and visual arts may be accurately described in this manner, and even the function for philosophers is very close to positive monotonic (Simonton, 2014b).

Consequently, researchers can find both positive and negative associations depending on which part of the distribution is actually sampled in their investigation. For example, creative geniuses can be more at risk than are their far less prolific or innovative colleagues. This expectation would explain the higher rates of psychopathology often found in historiometric research (Simonton, 2014a). In contrast, psychometric studies will more likely sample much less eminent creators who enjoy higher mental health, creating an apparent contradiction when none exists.

Naturally, it is reasonable to ask *why* this paradoxical finding might actually appear. Possible explanations fall into two categories. First, the cognitive and personality *antecedents* of genius-level creativity may put the individual at increased risk for psychopathological symptoms. For instance, higher creativity may require greater cognitive disinhibition, an inclination also associated with tendencies toward psychopathology (Carson, 2014). Second, a highly prolific and creative career may have *consequences* that can threaten mental health, such as increased criticism and even hostility in the reception of those products. It may be no accident that positive creativity-psychopathology relationships have most often been found in low-consensus domains where immediate appreciation by colleagues or audiences is by no means guaranteed, such as the expressive arts (Simonton, 2014b). The struggling and neglected artist is proverbial.

Ultimately, these possible outcomes and potential interpretations must be addressed by empirical research, but that research must have a more complex understanding of the questions asked.

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Is there an inverted-U relationship between creativity and psychopathology?

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Keywords: top down control, information processing, creative cognition, mental illness, divergent thinking, psychopathology, creativity, inverted-U function

A commentary on the Research Topic

Madness and Creativity: Yes, No or Maybe?
Edited by Anna Abraham

Few issues polarize the scientific community within the field of creativity as the purported association between creativity and psychopathology. The idea that the two are intimately linked dates back to Greek antiquity where the mental state of creative individuals during idea generation was noted to be highly aberrant. However, such eccentric states were not held to reflect clinical levels of mental illness until the 1800s (Becker, 2001).

The intuitive appeal of this connection partly stems from the commonalities we associate with mental illness and creativity, including a high tolerance for ambiguity, the ability to generate non-generic conceptual connections, and the adoption of alternative perspectives (Abraham, in press). Moreover, higher than average incidences of mental illness are found among people who practice professions that demand high levels of creativity, such as visual artists and writers (Kyaga et al., 2011; Simonton, 2014). The information processing mechanism that is generally proposed as underlying the link between creativity and psychopathology is that shortcomings during normative cognition (e.g., cognitive disinhibition), that are characteristic of certain psychiatric populations (e.g., psychosis), may translate to benefits in the context of creative cognition (Carson, 2011).

There are, however, also good grounds to be skeptical of the "mad genius" meme, which some argue is a quixotic notion at best (Schlesinger, 2009). For one thing, many of the studies that have been used to support this idea have come under a lot of criticism on methodological counts (Thys et al., 2014). Some have even shown that the presence of psychopathological traits explains only a paltry amount of the variance in creative performance (Silvia and Kimbrel, 2010). In addition, notwithstanding notable exceptions (e.g., van Gogh), individuals who achieved creative eminence in their fields were not operating at peak levels of productivity when they reached the point of severe mental illness.

So how can we make sense of this picture given that the evidence of a positive relationship between creativity and mental illness is clearly mixed? One approach would be to breakdown the empirical investigations that have assessed this link into meaningful categories based on a specific criterion and to evaluate whether any systematic patterns emerge as a result.

The madness-creativity link has, for instance, been investigated by assessing the performance of both psychiatric populations as well as subclinical populations on measures of creativity (Kaufman, 2014). The most well studied psychiatric populations in this regard include individuals with schizophrenia, bipolar disorder, attention deficit hyperactivity disorder (ADHD) and autism. Subclinical populations have also been widely assessed, and these refer to high risk healthy populations who are defined as such because they exhibit a high degree of mental illness-relevant personality traits. The rationale behind investigating subclinical groups is that studying high-functioning individuals who show some degree of predisposition for a clinical disorder enables us to understand the workings of the information processing biases related to that disorder without the burden of having to control for variables that can exert a confounding effect in studies on clinical populations (e.g., medication). Indeed, much evidence points to similarities in the information processing biases (e.g., latent disinhibition) typical of specific clinical groups (e.g., schizophrenia) and their respective subclinical populations (e.g., high psychoticism or schizotypal groups).

One means by which the creativity-psychopathology link can be investigated then is to focus on investigations of populations that are documented to have similar information processing biases and to cluster these studies by the type of population (clinical/subclinical) and the severity of disorder (high/low dysfunction). Let's take the premise that reduced top-down down control (influence of knowledge and expectations) on information processing can have a facilitative or debilitative effect on creative cognition. A number of psychiatric populations, such as ADHD and schizophrenia, are associated with poor top-down control and corresponding fronto-striatal dysfunction (Bradshaw and Sheppard, 2000),

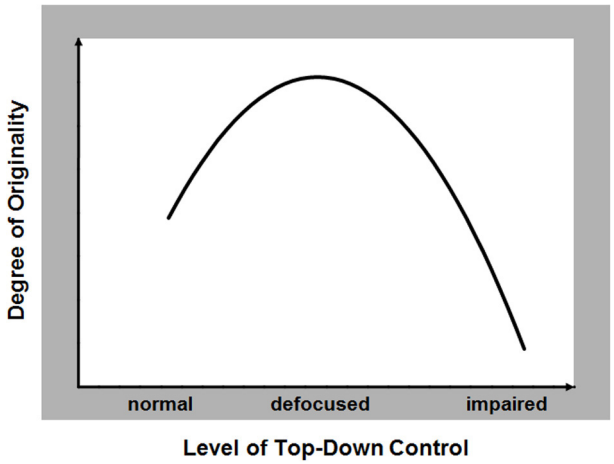

FIGURE 1 | The hypothesized relationship between the capacity to generate original responses during creative thinking (range: low to high) and the degree of functionality in top-down control of information processing (range: normal to impaired).

but these vary greatly in terms of severity. ADHD is associated with top-down deficits such as high levels of distractibility, impulsivity and poor inhibitory control functioning. But these are mild relative to those typically associated with schizophrenia within domains like executive function, working memory, inhibitory control and fluency. Milder still are negative biases in top-down control, such as latent disinhibition, that have been reported in subclinical groups. So does any viable pattern emerge when clustering the findings of such behavioral and neuropsychological studies according to the degree and/or type of top-down insufficiencies: clinical-severe, clinical-moderate, and subclinical-mild?

A number of studies on subclinical-mild populations, such as individuals who are characterized by the presence of a high degree of either schizotypal or psychoticism traits, have demonstrated that they consistently perform better than their low trait counterparts on some measures of creativity (Schuldberg, 2005; Acar and Sen, 2013). The same is true of populations who display clinical-moderate levels of top-down dysfunction, such as ADHD (Abraham et al., 2006; Healey and Rucklidge, 2006). In contrast, populations who are characterized by clinical-severe levels of top-down dysfunction, such as schizophrenia, perform poorly on almost all measures of creativity (Abraham et al., 2007; Jaracz et al., 2012). This pattern of findings suggests that while subclinical-mild and clinical-moderate levels of top-down dysfunction can, under specific conditions, confer selective advantages in creative cognition, clinical-severe levels of top-down dysfunction leads to impoverished creative thinking. A minimal level of function is probably essential to develop the original ideas one generates into something more tangible than a fleeting thought.

The effects of alterations in top-down control on creative performance can therefore be parsimoniously conceptualized in terms of an inverted-U shaped function or an inverted backward-J function (**Figure 1**). Direct investigations are necessary to reveal the precise pattern of this relationship. While diffuse or defocused top-down control in information processing may abet creative cognition, too much (normal) or too little (defective) top-down control can hinder or disrupt the same (Abraham, in press). An inverted-U function in this context is postulated to account for the abundance of conflicting findings associated with investigating the creativity-psychopathology link. The strength of this hypothesis is that it is one that readily lends itself to empirical investigation.

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Do dimensional psychopathology measures relate to creative achievement or divergent thinking?

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Previous research provides disparate accounts of the putative association between creativity and psychopathology, including schizotypy, psychoticism, hypomania, bipolar disorder, ADHD, and autism spectrum disorders. To examine these association, healthy, non-clinical participants completed several psychopathology-spectrum measures, often postulated to associate with creativity: the Schizotypal Personality Questionnaire, the Psychoticism scale, the Personality Inventory for DSM-5, the Hypomanic Personality Scale, the Attention Deficit/Hyperactivity Disorder scale, the Beck Depression Inventory, and the Autism-Spectrum Quotient. The goal of Study 1 was to evaluate the factor structure of these dimensional psychopathology measures and, in particular, to evaluate the case for a strong general factor(s). None of the factor solutions between 1 and 10 factors provided a strong fit with the data based on the most commonly used metrics. The goal of Study 2 was to determine whether these psychopathology scales predict, independently, two measures of creativity: 1. a measure of participants' real-world creative achievements, and 2. divergent thinking, a laboratory measure of creative cognition. After controlling for academic achievement, psychoticism and hypomania reliably predicted real-world creative achievement and divergent thinking scored with the consensual assessment technique. None of the psychopathology-spectrum scales reliably predicted divergent thinking scored with the manual scoring method. Implications for the potential links between several putative creative processes and risk factors for psychopathology are discussed.

Keywords: creativity, psychopathology, individual differences, divergent thinking, creative achievement

INTRODUCTION

"Creativity is a divine madness, a gift from gods" Plato famously declared (cited in Neihart, 1998, p. 1), yet to this day the debate on whether creativity is associated with psychopathology remains unsettled. Research provides varying accounts of the putative associations between creativity and psychopathology, with the disparity possibly due to methodological issues, such as small, highly specialized samples of eminent creators, or dependence on subjective and anecdotal accounts (e.g., Andreasen, 1987; Jamison, 1989, 1995; Ludwig, 1995). The seemingly heterogeneous results might also be due to heterogeneous study designs and varying measurements of psychopathology and creativity (for review, Thys et al., 2014).

Nevertheless, empirical evidence exists for the association between creativity and a variety of psychopathology spectrum measures, in both clinical and non-clinical samples. Creativity, for example, is reported to relate to schizotypy and psychosis measures (e.g., Andreasen and Powers, 1975; Abraham et al., 2005). Artists are elevated on schizotypy—a set of characteristics related to schizophrenia (Eckblad and Chapman, 1983; Nelson and Rawlings, 2008). People with increased schizotypy are also better at overcoming the constraining influence of examples when trying to generate original responses on a divergent thinking task compared to people with lower schizotypy scores (Abraham and Windmann, 2008). Higher levels of psychoticism accompany a greater degree of conceptual expansion and elevated levels of originality in creative imagery (Abraham et al., 2005).

Creativity appears to also be associated with atypical attention: adults diagnosed with ADHD are suggested to have higher real-world creative achievements (White and Shaw, 2011), and outperform those without ADHD on divergent thinking tasks (White and Shaw, 2006). Creativity has also been linked with autism and the milder form of autism, Asperger's syndrome, particularly among writers, artists, and musicians, such as Lewis Carroll (Fitzgerald, 2004), Vincent Van Gogh, Glenn Gould (James, 2006), and Erik Satie (Fung, 2002).

Finally, mood disorders and creativity have been associated. Three different measures of creativity—divergent thinking, self-rated creativity, and biographical inventory of creative behaviors relate to hypomanic traits (Furnham et al., 2008). Writers are more likely to be diagnosed with unipolar depression (Kyaga et al., 2013). Bipolar disorder and schizotypy also seem to affect occupational choice and fit. Bipolar disorder, for example, is associated with engagement in creative professions in both artistic and scientific domains in a large sample (the Swedish total population register, Kyaga et al., 2013). In the same population, individuals with schizophrenia, schizoaffective disorder, unipolar depression, anxiety disorders, alcohol abuse, drug abuse, autism, ADHD, and/or suicidality had a reduced likelihood of being engaged in creative professions.

These findings may suggest that the more extreme versions of psychological disorders are not conducive to being engaged in creative professions. Milder versions, however, such as subclinical mania/depression, schizotypy, or Asperger's syndrome (possibly in combination with protective factors such as working memory, motivation, and grit (Duckworth et al., 2007), as well as other personality and environmental factors), may facilitate creative thinking without causing difficulties when engaged in the professional world. It has even been postulated that certain psychopathologies remain in the population precisely because they provide benefits of creativity to people with milder versions of the disorders, and their relatives (O'Reilly et al., 2001; Nettle, 2006). In support, psychologically healthy biological relatives of people with schizophrenia are more likely to participate in creative jobs and hobbies and tend to show higher levels of schizotypal personality traits compared to the general population (Kinney et al., 2001).

Work from multiple laboratories investigating the neuroscience of creative cognition has also suggested a link between psychopathology and creativity. Higher divergent thinkers, for instance, have lower levels of fractional anisotropy within left inferior frontal white matter (Jung et al., 2010), similar to people with schizophrenia and bipolar disorder (McIntosh et al., 2008; Sussmann et al., 2009). Additionally, both people with increased schizotypy and people with higher divergent thinking scores (emphasizing originality) exhibit reduced deactivation of the right precuneus when generating ideas (the right precuneus is thought to be responsible for gathering external and internal information Fink et al., 2014), thus both groups show similar brain patterns during idea generation.

Although numerous measures of creativity exist, divergent thinking tests and assessments of real-world creative achievements are the two commonly used measures. Divergent thinking tests assess the ability to generate many novel and appropriate responses to a given problem within a limited time (e.g., Guilford, 1967; Torrance, 1974; Goff and Torrance, 2002). A common example is the alternate uses task, which requires generating creative uses for common objects such as a brick. The process of divergent thinking corresponds to the general concept of creative idea generation. There are many possible responses to this task and people differ in the fluency (number of responses), and originality/novelty of their responses (Guilford, 1950; Runco and Acar, 2012). Divergent thinking is thought to rely on cognitive processes such as "the retrieval of existing knowledge from memory and the combination of various aspects of existing knowledge into novel ideas" (Paulus and Brown, 2007, p. 252; also see, Mednick, 1962).

Creative achievement questionnaires tally creative behaviors and outcomes. The Creative Achievement Questionnaire (CAQ; Carson et al., 2005) prompts participants to indicate prior achievements of various types in 10 (artistic and scientific) creative domains. Domain scores are summed to form a single index of creative achievement. Creative achievement is assumed to reflect not only creative ability, but also motivation, persistence, opportunity, and resources.

While creative achievement and divergent thinking are typically modestly correlated, our previous investigations suggest that there are reliable differences in how creative achievers and divergent thinkers attend to environmental stimuli and process sensory information. Real-world creative achievers appear to have broad or "leaky" attention, as well as leaky sensory filters, as assessed by the P50 event-related potential (ERP; Zabelina et al., submitted, under revision). Divergent thinking, on the other hand, is linked with the ability to focus and shift attention, supporting attentional flexibility, as well as with highly selective sensory filters, as assessed by the P50 ERP (Zabelina et al., submitted, under revision).

It is not surprising that divergent thinking is associated with focused attention. Divergent thinking tests assess the ability to generate new and appropriate responses to a given problem within a limited time—typically within 2–3 min (e.g., Guilford, 1967; Torrance, 1974; Goff and Torrance, 2002). Responses are scored for fluency (number of responses), and originality/novelty of responses, with the total divergent thinking score reflecting a weighted total of fluency and originality combined, as suggested by the scoring manual (Goff and Torrance, 2002; also see Guilford, 1950; Runco and Acar, 2012). Therefore, people who are able to quickly provide a response, inhibit the just-given response, and quickly move on to the next response are the ones with the higher divergent thinking scores. Indeed, divergent thinking scored by this method has recently been suggested to depend on the overall executive processes (Gilhooly et al., 2007; Nusbaum and Silvia, 2011; De Dreu et al., 2012; Wiley and Jarosz, 2012), i.e., general-purpose control mechanisms such as the ability of the cognitive system to configure itself for the performance of specific task goals (Botvinick et al., 2001; Miyake and Friedman, 2012).

An alternative methods of scoring divergent thinking tests is the Consensual Assessment Technique (CAT; Amabile, 1982). Here independent judges subjectively rate each participant's responses according to their own notion of "creativity." We employed both the standard scoring method based on the manual, as well as the CAT method to score our divergent thinking tests.

Real-world creative achievements, on the other hand, may reflect a different type of creativity, as they encompass more than just the ability to think in a divergent manner. There are many differences between timed laboratory tests of divergent thinking and real world creative achievement. The latter requires both the generation of an original idea and some level of investment into its further development. Differences between measures of divergent thinking and creative achievement therefore reflect differences in the time course of the process, motivation, resources, and other factors.

In the current study we examine whether sub-clinical levels of psychopathology in a healthy non-clinical sample are associated with real-world creative achievement (CAQ: Carson et al., 2005) or divergent thinking (Goff and Torrance, 2002). Based on our prior results, we expected divergent thinking scored with the manual method and real-world creative achievements to differentially relate to psychopathology-spectrum measures. Divergent thinking scored with the CAT method and creative achievement, on the other hand, should show similar pattern of results, given that the CAT method emphasizes general creativity. First, we examined the internal structure of our psychopathology measures, and, in particular, evaluated the case for a strong

general factor(s) (Study 1)—this was done in order to evaluate the perception that creativity is associated with "madness." We then investigated whether the psychopathology-spectrum measures often found to be associated with creativity differentially predict divergent thinking and creative achievement (Study 2).

An important feature of creative ability is intelligence (Sternberg and O'Hara, 1999), as the literature consistently reports a positive association between intelligence and creativity (Batey and Furnham, 2006; Kim et al., 2010). To account for this association, we used academic achievement test percentile scores (Scholastic Assessment Test (SAT) or American College Testing (ACT); College Board, 2012; ACT Inc., 2014) as a proxy for general intelligence to factor out a general common factor between creative achievement, divergent thinking, and intelligence.

STUDY 1

METHODS

Participants

One hundred participants ages 18–30 (mean age = 20.55, *SD* = 2.51, male/female = 33/67) took part in the present study. None of the participants had been hospitalized for psychiatric or neurological reasons, and none abused alcohol or drugs. Two participants had history of depression (one in the past, but in remission at the time of the study; one current, treated with Zoloft); one had dysthymia (current, but not taking medication); one had mild anxiety (current, no medication). Seven participants had first-degree relatives with diagnosed psychiatric illnesses. The relations were: a sister with Bipolar I Disorder, anxiety, and psychotic features (auditory hallucinations); a mother with mild depression; a father with depression; a mother with depression; a mother with depression; a twin sister with depression; a mother with Bipolar Disorder, and a father with depression.

All subjects were Caucasian, and right-handed, as assessed by the Chapman Handedness Questionnaire (Chapman and Chapman, 1987). Participants completed an informed consent prior to participating in the study and received $20 for their participation. The study was approved by the Institutional Review Board of Northwestern University.

Procedure

Participants were tested individually, with each session lasting up to 2 h, as part of a larger experimental session. Participants first completed the divergent thinking test, followed by the battery of questionnaires. Other tests were administered as part of the study, such as the Compound Remote Associates (CRA) test, but data did not prove to be reliable, and therefore are not included in this report.

Measures

Schizotypal Personality Questionnaire (SPQ: Raine, 1991) is a self-report scale modeled on DSM-III-R criteria for shizotypal personality disorder. The SPQ consists of twenty-two items with binary choice responses: "yes" and "no." The SPQ has high sampling validity, high internal and test-retest reliability, convergent, discriminant, and criterion validity (Raine, 1991). Example statements include "I am an odd, unusual person," and "I feel I have to be on my guard even with friends." One participant had missing SPQ data. The mean SPQ score was 7.84 (*SD* = 4.84, range 0–19).

The Psychoticism Scale of the PID-5 (PID5-P: Krueger et al., 2011) was developed for the DSM-5 in order to assess traits that may or may not constitute a formal personality disorder. The PID5-P consists of 34 statements that are answered on a 4-item Likert scale, from "Very often or often false" to "Very true or often true." Example statements include "I often have thoughts that make sense to me but that other people say are strange," and "Sometimes I get this weird feeling that parts of my body feel like they're dead or not really me." The mean PID5-P score was 1.72 (*SD* = 0.46, range 1.0–3.0).

Hypomanic Personality Scale (HPS: Eckblad and Chapman, 1986) is designed to identify people with hypomanic personality. The HPS consists of 48 statements with binary choice responses: "True" and "False." Example statements include "I am frequently in such high spirits that I can't concentrate on any one thing for too long," and "My moods do not seem to fluctuate any more than most people's do (reverse-scored)." The mean HPS score was 16.18 (*SD* = 7.31, range 3–36).

Adult ADHD Self-Report Scale (ASRS-vI.I: Kessler et al., 2005) scale is consistent with DSM-IV criteria and addresses the manifestations of ADHD symptoms in adults. It consists of eighteen questions, and is answered on a 5-item Likert scale, from "Never" to "Very often." Example questions include "How often do you leave your seat in meetings or other situations in which you are expected to remain seated?" and "How often do you make careless mistakes when you have to work on a boring or difficult project?" The ADHD mean score was 2.23 (*SD* = 0.53, range 1.4–4.3).

Beck Depression Inventory (BDI: Beck et al., 1996) is designed to reflect how a person is feeling at the moment, and comprises twenty items, with 4–7 choices per item. Example statements include: "Sadness: I do not feel sad (0), I feel sad much of the time (1), I am sad all the time (2), I am so sad or unhappy that I can't stand it (3)," and "Loss of interest: I have not lost interest in other people or activities (0), I am less interested in other people or things than before (1), I have lost most of my interest in other people or things (2), It's hard to get interested in anything (3)." Four participants had missing BDI data. The BDI mean score was 9.97 (*SD* = 7.39, range 0–30).

Autism-Spectrum Quotient (ASQ; Baron-Cohen et al., 2001) assesses the degree to which adults with normal intelligence have traits associated with the autistic spectrum. The ASQ consists of 50 questions, with four response options from "definitely agree" to "slightly disagree." Approximately half of the statements score 1 point for "definitely agree" or "slightly agree" responses, while the other half of the statements score 1 point for "definitely disagree" or "slightly disagree" responses. The ASQ measure exhibits good test-retest and inter-rater reliability. Example statements include "I prefer to do things the same way over and over again" and "I enjoy social chit-chat (reverse-scored)." One participant had missing ASQ data. The ASQ mean score was 17.85 (*SD* = 6.45, range = 5–35).

ANALYSIS

Internal consistencies and general factor saturation for each of the psychopathology scales was assessed using the Pearson correlations between items to calculate the α, ω total, and ω hierarchical coefficients (Zinbarg et al., 2005; Revelle and Zinbarg, 2009; Revelle, 2014). Given the absence of *a priori* predictions regarding the underlying structure of these scales, latent variable exploratory factor analyses were conducted based on responses to all the items of the six dimensional psychopathology measures. These EFAs were based on the Pearson correlations between scored responses using Ordinary Least Squares regression models with oblique rotation (Revelle, 2014). Factor solutions were considered for EFAs, which extracted between 1 and 10 factors. Goodness-of-fit was evaluated using the "nfactors" function in the *psych* package (Revelle, 2014) in the R computing environment (R Core Team, 2014), which generates fit statistics based on a wide range of methods, including the Root Mean Squared Error of Approximation (RMSEA; Hu and Bentler, 1999), the empirically-derived root mean square of the residual corrected for degrees of freedom (Kenny, 2014), and the Bayesian Information Criterion (BIC; Kenny, 2014). Evaluation of the factor structure also made use of parallel analyses, which compares "scree" plots of the eigenvalues based on observed data with those from a random matrix of simulated data of the same size and number of observations (Revelle, 2014). It should be noted that 200 or more pairwise administrations between items are recommended when conducting exploratory factor analyses of this nature as smaller samples will often suffer from instability among the correlations. Evaluation of the KMO measure of sampling adequacy (Kaiser and Rice, 1974) demonstrated that the correlation matrix was not invertible, a circumstance which frequently results from instability. As such, the results of the EFAs reported here should be considered preliminary rather than conclusive. In addition, mean item communalities have been included with the fit statistics for each of the factor solutions shown.

RESULTS

Internal consistencies for each of the psychopathology measures are reported in **Table 1**. The α values were high for all of the scales, ranging from 0.80 to 0.94, and these values were generally consistent with the ω total values. Values for the ω hierarchical measure of general factor saturation varied considerably, ranging from low values of 0.45 and 0.49 for the ASQ and SPQ, respectively, to relatively high values of 0.66 and 0.68 for the PID5-P and the BDI.

Table 1 | Alpha, omega hierarchical and omega total for the psychopathology scales.

	α	ω hierarchical	ω total	Items
ADHD	0.85	0.56	0.88	18
ASQ	0.86	0.45	0.89	50
BDI	0.85	0.68	0.88	20
HPS	0.80	0.63	0.83	48
PID5-P	0.94	0.66	0.95	33
SPQ	0.83	0.49	0.86	22

Fit statistics are reported in **Table 2** based on the extraction of 1–10 factors from the correlations of scores between items in all six of the psychopathology scales. **Figure 1** depicts plots of the fit statistics as well as the eigenvalues for the actual and simulated data. Both the RMSEA and the empirically-derived root mean square residual suggest that none of the factor solutions provide a strong fit. This is consistent with the BIC, which does not reach a localized minimum at fewer than 10 factors, and the parallel analysis, for which the eigenvalues based on factoring of the actual data fail to cross below those which would be expected based on simulated random data.

Visual inspection of the plots in **Figure 1** provide some evidence to support the two (and perhaps three) factor solution(s). **Table 3** shows the most highly loaded items for each factor of the two-factor solution. While the organization and loadings of the items varied according to the number of factors extracted, factors with similar content ("Unusual behavior" and "Social awkwardness") were found in each of the factor solutions from 3 to 10 factors. The highest loaded items in the third factor for the three factor solution were "I am frequently so 'hyper' that my friends kiddingly ask me what drug I'm taking," "I am considered to be kind of a 'hyper' person," and "People often look at me as if I'd said something really weird."

DISCUSSION AND STUDY 2

While the traditional measure of internal consistency (alpha) was more than adequate for all of the scales independently, the evidence for a strong general factor was low for the ASQ scale, the SPQ scale, and, to a lesser extent, the ADHD scale. This suggests that these scales have multidimensional factor structures by themselves and that the use of single scale level scores for these measures will not distinguish between variability across the underlying constructs. While the presence of low general factor saturation on some measures does not allow for any conclusions to be drawn about the factor structure underlying the full set of items across all the scales, it does support the

Table 2 | Fit statistics based on extraction of 1 to 10 factors.

Factors extracted	RMSEA	eBIC	eSRMR	Mean h^2
1	0.205	−5.708	0.147	0.18
2	0.158	−31.491	0.118	0.27
3	0.143	−36.976	0.111	0.31
4	0.131	−41.013	0.104	0.35
5	0.122	−43.955	0.099	0.39
6	0.113	−46.195	0.095	0.42
7	0.105	−47.877	0.091	0.45
8	0.098	−49.312	0.087	0.48
9	0.092	−50.236	0.084	0.50
10	0.085	−51.115	0.081	0.53

RMSEA, root mean square error of approximation; eBIC, empirically-derived Bayesian Information Criterion; eSRMR, empirically-derived root mean square of the residual corrected for degrees of freedom. mean h^2 is the mean communality across items in the solution where communality is the sum of the squared loadings.

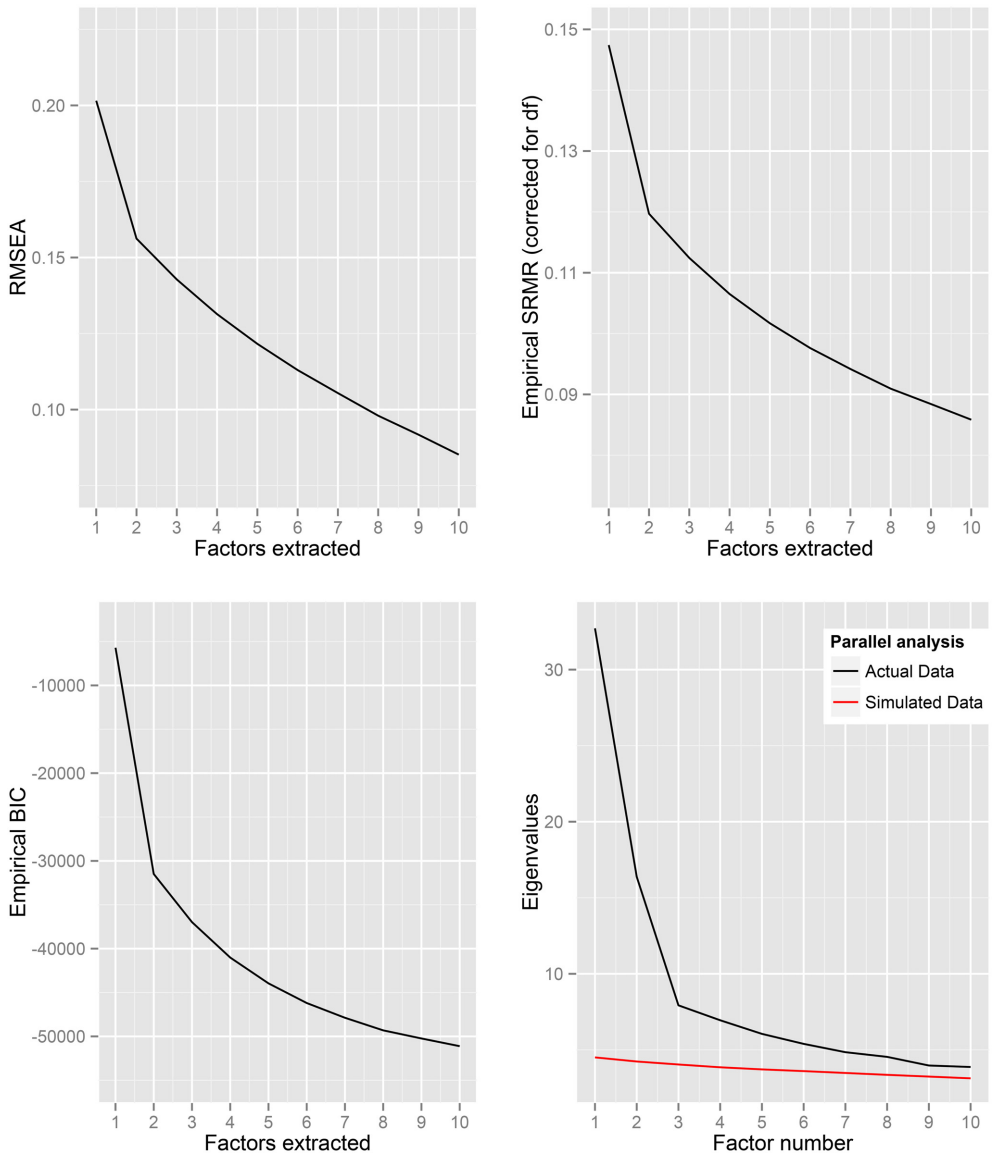

FIGURE 1 | Fit statistics and eigenvalues based on extraction of 1 to 10 factors from the correlations between all of the psychopathology measures.

need for further investigation of structure across and within scales.

Analyses of the factor structure across the scales were largely inconclusive. None of the factor solutions between 1 and 10 factors provided a strong fit with the data based on the most commonly used metrics. For the RMSEA and the empirically-derived root mean square of the residual, only the 10 factor extraction began to approach mediocre fit values (Kenny, 2014). BIC values improved (as expected) as more factors were extracted, but failed to reach a local minimum. This implied that more than 10 factors are needed to fit the items of these six psychopathology scales.

Examination of the item content in the two most consistent factors showed that one of these mapped onto the PID5-Psychoticism scale and the second was comprised of sociability items from a wide variety of scales. Given the poor fit of these factor analytic solutions and the content of the resultant factors, there was little justification for the prospect of correlating creative achievement and divergent thinking scores with factors scores derived from joint administration of these six psychopathology scales. This does not, however, preclude the possibility of evaluating the relationship between the scale scores for these six constructs, creative achievement, and divergent thinking.

METHODS

Study 2 included the same participants, procedure, and methods as in Study 1. In addition, Study 2 incorporated divergent thinking, real-world creative achievement, and academic achievement scores.

Table 3 | Most highly loaded items for each factor of the two-factor solution.

Item	Loading	Scale
FACTOR 1		
Other people seem to think my behavior is weird.	0.75	PID5-P
Others seem to think I'm quite odd or unusual.	0.75	PID5-P
People often look at me as if I'd said something really weird.	0.72	PID5-P
I often have ideas that are too unusual to explain to anyone.	0.70	PID5-P
I often have thoughts that make sense to me but that other people say are strange.	0.68	PID5-P
My thoughts are strange and unpredictable.	0.68	PID5-P
People have told me that I think about things in a really strange way.	0.67	PID5-P
Have you had experiences with astrology, seeing the future, UFOs, ESP or a sixth sense?	0.67	Schizotypy
I think about things in odd ways that don't make sense to most people.	0.65	PID5-P
My thoughts often don't make sense to others.	0.65	PID5-P
FACTOR 2		
I tend to keep in the background on social occasions.	−0.81	SPQ
I find social situations easy.	0.79	ASQ
When I go to a gathering where I don't know anyone, it usually takes me a while to feel comfortable.	−0.77	HPS
I am good at social chit-chat.	0.75	ASQ
I feel very uncomfortable in social situations involving unfamiliar people.	−0.73	SPQ
I feel very uneasy talking to people I do not know well.	−0.72	SPQ
I enjoy social occasions.	0.72	ASQ
At social gatherings, I am usually the "life of the party."	0.70	HPS
I find it hard to make new friends.	−0.68	ASQ
New situations make me anxious.	−0.67	ASQ

Measures

Abbreviated torrance test for adults (ATTA: Goff and Torrance, 2002). Divergent thinking was assessed by the Abbreviated Torrance Test for Adults (ATTA: Goff and Torrance, 2002)—a shortened form of the Torrance Test of Creative Thinking (Torrance, 1974). The ATTA consists of three activities (3 min each), one involving written responses (e.g., naming problems that may arise from being able to walk on air or fly without being in an airplane or a similar vehicle), and two involving figural responses (e.g., using incomplete figures to make pictures).

Responses were scored in the standard way of scoring the ATTA according to the manual (Goff and Torrance, 2002). Here, responses were scored for fluency (i.e., a count of the number of pertinent responses), and originality (i.e., the number of responses that are unique or original), with the total scores summed across the three activities (Goff and Torrance, 2002). We computed a total divergent thinking (ATTA manual) score by summing fluency plus two times originality (to equally weight the two scores, since the average fluency score [14.1] was approximately double the average originality score [7.2]. See Runco and Acar (2012) for suggestions on scoring divergent thinking tests). Note that this scoring methods takes into account the number of responses generated by participants, as well as the originality of responses. Two participants had missing ATTA scores.

In addition to scoring ATTA responses according to the manual, responses were also scored with the consensual assessment technique (CAT; Amabile, 1982). Four independent raters (all female) ranked the responses of each participant on the Likert scale (1 = not at all creative, 5 = very creative), from which a total divergent thinking (ATTA CAT) score was derived. The raters were of the same cohort as the participants (19–25 years old), and agreed in their ratings (Cronbach's Alpha = 0.87). Note that the CAT technique's focus is on the subjective creativity of responses, without taking into account the number of responses generated by participants.

Creative achievement questionnaire (CAQ: Carson et al., 2005). We assessed real-world creative behavior with the Creative Achievement Questionnaire, a survey on which participants cataloged any prior creative achievements across ten creative domains (visual art, music, dance, architectural design, creative writing, humor, inventions, scientific discovery, theater and film, and culinary arts). In the Music domain, for example, questions range from "I have no training or recognized talent in this area" (score of 0) to "My compositions have been critiqued in a national publication" (score of 7). In the Scientific Discovery subset, scores vary from "I have no training or recognized ability in this field" (score of 0) to "My work has been cited by other scientists in national publications" (score of 7). Separate domain scores were then combined to form a single index of creative achievement ($M = 13.66$, $SD = 11.08$, min = 0, max = 48). One participant had missing CAQ data. CAQ scores were positively skewed, therefore we used the signed log transformation to normalize the CAQ distribution.

Academic test scores. Participants provided their SAT or ACT scores, depending on which achievement test they took. These were converted into percentile scores based on the national statistics in 2012 ($M = 97.94$, $SD = 2.20$, min = 87, max = 100; College Board, 2012; ACT Inc., 2014). In prior studies in our laboratory, self-reported scores were confirmed with actual

scores through the admissions office, and the two correlated $r = 0.97$ (Wegbreit et al., 2012). Twenty-eight people did not report their academic test scores (therefore degrees of freedom will be different when academic test scores are included in the analyses).

ANALYSIS

The goal of Study 2 was to determine whether psychopathology-spectrum scales predict, independently, creative achievement and divergent thinking. Given that there was no clear underlying common structure within the psychopathology-spectrum scales, we performed separate linear regression analyses predicting divergent thinking and creative achievement, while controlling for academic achievement scores.

Given prior findings in the literature, as well as our previous investigations suggesting that creative achievement is associated with leaky attention, as well as with reduced sensory gating, we expected traits associated with psychosis, such as schizotypy (SPQ) and psychoticism (PID5-P), to predict creative achievement. We also reasoned that hypomania (HPS) should predict creative achievement, given prior evidence (Furnham et al., 2008), and that drive and energy are needed to have a large number of creative achievements in the real world (especially in our undergraduate sample).

Our previous investigations also suggest that divergent thinking is associated with selective attention, as well as with more selective sensory gating, therefore we did not expect divergent thinking to relate to any psychopathology-spectrum measures.

RESULTS

Psychopathology spectrum traits and creativity

Zero-order correlations between psychopathology-spectrum scales, creative achievement, divergent thinking (ATTA manual and ATTA CAT), and academic achievement scores are reported in **Table 4**, along with the 95% confidence intervals of the correlations. The correlation between creative achievement and divergent thinking scored manually did not significantly differ from zero, though the correlation was significant between creative achievement and divergent thinking when scored with the consensual assessment technique ($r = 0.32$, $p < 0.01$). Both scoring methods were significantly associated with academic achievement scores (ATTA CAT $r = 0.22$, $p = 0.01$; ATTA manual $r = 0.19$, $p = 0.03$). There was no association between creative achievement and academic achievement scores.

With respect to the psychopathology spectrum scales, creative achievement was significantly correlated with HPS ($r = 0.43$, $p < 0.001$), PID5-P ($r = 0.29$, $p < 0.01$), and ADHD ($r = 0.25$, $p = 0.01$). Both methods of scoring divergent thinking were significantly correlated with HPS (ATTA manual $r = 0.26$, $p = 0.02$; ATTA CAT $r = 0.34$, $p < 0.001$). Only the consensual assessment technique for scoring divergent thinking was significantly correlated with the PID5P ($r = 0.24$, $p = 0.03$).

Multiple regression analyses controlling for academic achievement scores

Given that there was no clear underlying common structure between the psychopathology-spectrum scales, we performed separate linear regression analyses predicting creative achievement and divergent thinking, while controlling for academic achievement scores.

As expected, creative achievement was significantly predicted (after controlling for achievement test scores) by the PID5-P, $t_{(83)} = 2.69$, $p = 0.01$, $b = 0.28$; and the HPS, $t_{(83)} = 4.16$, $p < 0.001$, $b = 0.44$ (**Table 5**).

Controlling for achievement test scores, divergent thinking when scored with the consensual assessment technique was also significantly predicted by the PID5-P, $t_{(82)} = 2.44$, $p = 0.02$, $b = 0.25$, and the HPS, $t_{(82)} = 3.16$, $p < 0.001$, $b = 0.33$ (**Table 6**). When scored with the traditional manual method, divergent thinking was not significantly predicted by any of the psychopathology measures (**Table 7**).

Table 4 | Correlations among academic test scores (Ach Tests), divergent thinking (ATTA), and creative achievement (CAQ).

	Achievement tests	ATTA manual	ATTA CAT	CAQ	PID5P	SPQ	ADHD	BDI	HPS
ATTA Man.	0.19 (0.03–0.36)								
ATTA CAT	0.22 (0.04–0.37)	0.56 (0.43–0.68)							
CAQ	0.02 (−0.14–0.20)	0.15 (−0.04–0.36)	0.32 (0.15–0.47)						
PID5P	−0.04 (−0.23–0.15)	0.19 (0.00–0.38)	0.24 (0.05–0.42)	0.29 (0.13–0.46)					
SPQ	−0.01 (−0.21–0.26)	0.06 (−0.13–0.24)	0.09 (−0.09–0.30)	0.15 (−0.03–0.34)	0.72 (0.63–0.79)				
ADHD	0.07 (−0.09–0.25)	0.02 (−0.18–0.23)	0.00 (−0.20–0.18)	0.25 (0.06–0.44)	0.61 (0.48–0.70)	0.41 (0.25–0.52)			
BDI	−0.11 (−0.31–0.06)	−0.10 (−0.28–0.12)	−0.03 (−0.21–0.20)	0.06 (−0.12–0.23)	0.36 (0.22–0.54)	0.39 (0.21–0.58)	0.38 (0.27–0.54)		
HPS	0.07 (−0.07–0.21)	0.26 (0.07–0.47)	0.34 (0.19–0.49)	0.43 (0.27–0.56)	0.51 (0.31–0.67)	0.19 (0.02–0.38)	0.42 (0.21–0.59)	0.12 (−0.08–0.28)	
ASQ	0.15 (−0.12–0.36)	0.17 (−0.02–0.35)	0.18 (−0.02–0.41)	0.06 (−0.13–0.23)	−0.38 (−0.52– −0.23)	−0.61 (−0.72– −0.47)	−0.26 (−0.41– −0.10)	−0.40 (−0.56– −0.23)	0.11 (−0.06–0.27)

Values in parentheses indicate the 95% confidence interval of the correlations.

DISCUSSION

Here we systematically examined the presence of an underlying common structure within the psychopathology-spectrum scales often postulated to be associated with creativity (Study 1), and investigated whether these scales are associated with two aspects of creativity: 1. real-world creative achievement, and divergent thinking, a laboratory measure of creative cognition, scored by two different methods (Study 2).

Latent variable exploratory factor analyses of the factor structure across the scales were largely inconclusive. Examination of the item content in the two most consistent factors showed that one of these mapped onto the PID5-Psychoticism scale and the second was comprised of sociability items from a wide variety of scales. Given the poor fit of these factor analytic solutions, there was little justification for the prospect of correlating creative achievement and divergent thinking scores with factor scores. We therefore evaluated the relationship between the psychopathology-spectrum scale scores, creative achievement, and divergent thinking within separate multiple regression analyses. Controlling for academic achievement, real-world creative achievement was significantly predicted by psychoticism and hypomania. The association between real-world creative achievement and psychoticism supports the suggestion that milder forms of psychopathology, such as sub-clinical levels of psychoticism may indeed be adaptive for creativity (O'Reilly et al., 2001), while clinical levels of these disorders, such as psychosis, would presumably be maladaptive.

Creative achievement was predicted by psychochoticism, however, it did not relate to schizotypy in our sample, as it has in prior studies (Kinney et al., 2001; Abraham and Windmann, 2008). This result indicates that traits associated with psychoticism, such as impulsivity and sensation-seeking, may benefit creative achievement.

Creative achievement was also predicted by hypomania, indicating that high energy levels are associated with increased creative achievement in the real world. To be clear, predisposition to mental illness is neither *necessary* nor *sufficient* for creative achievement. There are numerous eminent creative people without mental illness, and multiple possibilities can explain the relationship between mental illness and creative eminence.

Divergent thinking scored with the CAT scoring method, which taps into the overall creativity of participants' responses, without taking into account the number of responses produced by participants, was reliably predicted by psychoticism and hypomania, controlling for academic achievement scores. Additionally, the CAT divergent thinking and creative achievement significantly correlated, whereas divergent thinking scored with the manual and creative achievement showed no reliable association. These results indicate that divergent thinking scored with the CAT technique is more closely linked with creativity in the real world.

Divergent thinking scored with the manual scoring method was not reliably predicted by any of the psychopathology-spectrum scales, and only marginally predicted by hypomania and autism-spectrum. Given that the manual scoring emphasizes not only the originality of participants' responses, but also their total number within a limited time, divergent thinking scored with this method may tap into the executive processes

Table 5 | Creative achievement as a function of psychopathology-spectrum scales, controlling for academic achievement scores.

Variable	*b*	SE *b*	*t*	*p*
SPQ	0.15	0.11	1.42	0.16
SAT/ACT	0.03	0.11	0.25	0.80
PID5P	0.28	0.1	2.69	0.01**
SAT/ACT	0.03	0.1	0.31	0.76
HPS	0.44	0.1	4.16	0.00**
SAT/ACT	0	0.1	0.01	0.99
ADHD	0.21	0.11	1.92	0.06
SAT/ACT	0	0.11	0.02	0.98
BDI	0.01	0.12	0.05	0.96
SAT/ACT	0.02	0.11	0.18	0.86
ASQ	0.06	0.11	0.56	0.58
SAT/ACT	0.01	0.11	0.11	0.92

* < 0.05, ** < 0.01.

Table 6 | Divergent thinking scored with the consensual assessment technique as a function of psychopathology-spectrum scales, controlling for academic achievement scores.

Variable	*b*	SE *b*	*t*	*p*
SPQ	0.09	0.11	0.78	0.44
SAT/ACT	0.22	0.11	2.03	0.05*
PID5P	0.25	0.1	2.44	0.02*
SAT/ACT	0.24	0.11	2.2	0.03*
HPS	0.33	0.1	3.16	0.00**
SAT/ACT	0.2	0.1	1.92	0.06
ADHD	−0.01	0.11	−0.13	0.90
SAT/ACT	0.22	0.11	2.04	0.04*
BDI	0.06	0.12	0.55	0.59
SAT/ACT	0.24	0.11	2.17	0.03*
ASQ	0.14	0.11	1.33	0.19
SAT/ACT	0.2	0.11	1.84	0.07

* < 0.05, ** < 0.01.

Table 7 | Divergent thinking scored with the manual scoring method as a function of psychopathology-spectrum scales, controlling for academic achievement scores.

Variable	*b*	SE *b*	*t*	*p*
SPQ	0.05	0.11	0.42	0.67
SAT/ACT	0.2	0.11	1.85	0.07
PID5P	0.16	0.1	1.52	0.13
SAT/ACT	0.2	0.11	1.87	0.07
HPS	0.19	0.1	1.8	0.08
SAT/ACT	0.18	0.11	1.68	0.10
ADHD	0.1	0.11	0.11	0.91
SAT/ACT	0.19	0.11	1.77	0.08
BDI	0.01	0.11	0.11	0.91
SAT/ACT	0.21	0.11	1.94	0.06
ASQ	0.14	0.11	1.3	0.20
SAT/ACT	0.17	0.11	1.59	0.12

* < 0.05, ** < 0.01.

that are needed to perform well on timed laboratory tests, where performance may be impeded by having sub-clinical forms of psychopathology.

Indeed, although undeniably a feature of the creative process, producing numerous responses on a divergent thinking test appears to be more executive in nature than previously thought (Nusbaum and Silvia, 2011). Divergent thinking, for example, is found to rely on focused attention (Zabelina et al., under revision), and selective sensory filters (Zabelina et al., submitted). Additionally, executive functions "updating," which is closely associated with the concept of working memory (Jonides and Smith, 1997), and "inhibition," or the ability to suppress a dominant, but irrelevant response (Miyake and Friedman, 2012), significantly predict divergent thinking, while "shifting"—the process of switching between different tasks or mental sets (Monsell, 1996), does not (Benedek et al., 2014). Divergent thinking is also found to correlate with inhibition defined either by performance on the Stroop task (Groborz and Neçka, 2003; Edl et al., 2014), or the random motor generation task (Benedek et al., 2012; Zabelina et al., 2012). Thus, it is not surprising that we did not find an association between the divergent thinking test (where the score is comprised of fluency and originality of responses) and sub-clinical levels of psychopathology.

Although it has been suggested that depressive states may be conducive to creativity by narrowing the focus of attention and selecting the most practical ideas to pursue, or persistence in confronting problems (Verhaeghen et al., 2005), we found that neither divergent thinking nor creative achievement in our sample was associated with depression.

There were several limitations to this study. First, findings from the analyses are limited by the sample size. Second, it is important to recognize that there are other features of psychopathology that may relate to creativity, such as personality trait Openness to Experience (Miller and Tal, 2007; DeYoung et al., 2012). Future studies will need to investigate the relationship between Openness and other "normal-range" personality traits with both creative achievement and psychopathology. Finally, both psychopathology and creative achievement would ideally be measured by informants. Future research should make use of such measures, although historically such measures have not been widely available.

CONCLUSION

Here we examined the associations between psychopathology-spectrum measures and creativity. The factor structure of psychopathology measures revealed no common underlying factors, based on the most commonly used metrics. Separate linear regression analyses revealed that, after controlling for academic achievement, psychoticism and hypomania reliably predicted real-world creativity, as well as subjective ratings of creativity on the divergent thinking test. None of the psychopathology-spectrum scales reliably predicted scores on the timed divergent thinking scored with the manual method. The link between creativity and psychopathology requires additional investigation to more precisely reveal the cognitive mechanisms that both unite and distinguish creative people from those with a psychiatric disorder.

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Challenges in determining whether creativity and mental illness are associated

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The existence of a relationship between "creativity" and unusual mental states has been speculated on for centuries, with a specific connection of "creativity" to "mental illness" since the 1830s (Becker, 2001). However, controversy remains about whether this relationship exists (e.g., Schlesinger, 2009). The main challenge in supporting this claim is that the statement itself is very general. In addition, there are a number of issues that contribute to unclarity within this literature.

One issue is the way in which "creativity" and "mental illness" are discussed. "Creativity" is a broad construct that has been defined and operationalized in various ways across the studies that have attempted to examine it. This variety is due to the fact that creativity is likely composed of various facets (Dietrich and Kanso, 2010), but has often been referred to as if it is a unitary construct (see Glazer, 2009, for discussion). Similarly, "mental illness" is a heterogeneous construct that not only encompasses multiple symptoms and diagnoses but reflects societal and cultural definitions and norms, resulting in changes to diagnostic criteria sets throughout the years. Researchers have tried to answer the question of whether a relationship between "creativity" and "mental illness" exists, but, as would be expected when tackling such a broad question, the approaches of each study have differed. In practice, both "creativity" and "mental illness" have been operationalized in every research study that has tackled this issue by recruiting a particular population and using a specific definition (whether articulated or not) of creativity in order to successfully examine the construct. But after the conclusions have been made, the titles and introductions of the next journal articles on the topic discuss the broad concepts of "creativity and mental illness" and/or cite references that studied one facet of creativity in a population to support an association with another facet of creativity in the same population without an explanation of why a similar finding would be expected. Thus, overlooking the details of what was actually studied in previous papers and drawing support from any study that refers to "creativity" even though it may represent a different facet of creativity makes it difficult to make clear-cut statements about a relationship between creativity and mental illness or even whether such a broad comparison is useful.

To foster examination of potential relationships between creativity and mental illness, it would be prudent to use a more systematic approach in which these constructs are made explicit in each study (Prentky, 2001). Given the diverse definitions and measures of creativity employed to date, a given study should focus on one of these definitions, describe why that definition is appropriate for study in a particular population, and use a measure that taps that particular facet of creativity. For example, Glazer (2009) proposed three possible models (1. different types of creativity each associated with a specific psychopathology, 2. creativity as a dimension, and 3. creativity as a unitary construct) for the creativity construct and how each would be associated with psychopathology. Using such a framework (or another that is similarly clearly defined) would expedite the process of answering the question about whether there is a relationship between mental illness and creativity.

Another issue that contributes to confusion in the field is the use of various "creativity measures" that measure different facets of creativity across studies. The results of individual studies are often generalized to an overall conclusion about "creativity" without discussion about how these facets may be related to each other. A goal in a given study would be to determine whether and how the creativity facet tested by the primary creativity measure is related to other frequently-used creativity measures, by including multiple measures of creativity. Using multiple creativity measures in one study would provide data for convergent and discriminant validity between the facets of creativity measured in that study.

A further step in defining the facet of creativity being studied would be to hypothesize whether additional cognitive mechanisms are relevant to the selected facet of creativity. Inclusion of cognitive measures (i.e., neuropsychological measures or behavioral tasks) that assess these mechanisms would allow determination of whether and how much creativity and cognitive measures overlap and allow integration and comparison of results to other literature that involves cognitive skills. For instance, Boden (2013) suggests that an understanding of associative pathways regarding semantic information and its relevance to context is important for creativity. Making semantic associations between words or concepts (likely associated with verbal creativity) has been related to executive function

and positive schizotypy (Fisher et al., 2007, 2013), somewhat consistent with Eysenck's (1993) theory that psychoticism (P) is mediated by high divergent thinking (often referred to as an aspect of creativity) and low inhibition. Other facets of creativity are likely related to other cognitive processes (e.g., use of spatial relationships, problem solving, pattern recognition, cognitive inhibition). Incorporating cognitive measures from these fields could help shed light on what creativity is, how it works and whether there are multiple mechanisms that lead to the same facet of creativity.

In addition to both a more explicit definition and operationalization of creativity and investigating its associated cognitive correlates, a study would be clearer about why a certain type of mental illness is being investigated in relation to that type of creativity. Many studies have investigated a relationship between creativity and the schizophrenia spectrum (e.g., Weinstein and Graves, 2002; Fisher et al., 2004; Folley and Park, 2005), bipolar disorders (e.g., Soeiro-de-Souza et al., 2011), hypomania (e.g., Furnham et al., 2008), depression and anxiety (e.g., Silvia and Kimbrel, 2010), and autism characteristics (e.g., Rawlings and Locarnini, 2008; Claridge and McDonald, 2009). However, these diagnoses differ from each other in addition to having heterogeneous presentations of symptoms within each diagnosis. Thus, when considered as a whole, it is unclear why all of these disorders would be associated with creativity, especially if creativity is a unitary construct as it is often referred. Examining one facet of creativity in more than one mental illness or symptom type within one study could assist in determining specificity of that facet to a particular symptom type. It is more likely that one symptom or a number of symptoms in combination, either common or unique to multiple diagnoses, would be associated with a particular facet of creativity than an overall diagnosis or mental illness as a whole.

Furthermore, any facet of creativity is unlikely to be associated with clinical levels of symptoms. For instance, some of the most consistent findings about associations between performance on creativity measures and psychopathology-spectrum symptoms have been in samples of individuals with subclinical schizoprehnia-spectrum characteristics (undergraduates with high scores on schizotypy or first-degree relatives of those who have been diagnosed with a mental disorder) and not those diagnosed with schizophrenia (e.g., Jaracz et al., 2012). Thus, mental illness is likely an invalid term.

As a final note, a study that incorporates measures of creativity, cognition and symptoms may have to rely on statistical methods that do not assume linearity. Associations between cognitive skills and a facet of creativity, between cognitive skills and symptoms, and between a facet of creativity and symptom constellations are likely quite complex; thus, it is unlikely that an association between all three would be linear. To support this statement, there is evidence that schizotypy characteristics and executive function are curvilinearly associated with semantic processing in an inverted U-shape (Fisher et al., 2013). Similarly, Abraham (2014) suggested that top-down control and originality are associated in this manner. These studies are akin to Nelson and Rawlings (2010) suggesting that creativity increases with moderate schizotypy and decreases with increased more serious psychopathology and Stoneham and Coughtrey (2009) finding that high and low schizotypy groups are faster to solve a creative problem-solving task than those in an intermediate schizotypy group. Reliance on statistical methods designed to detect linear relationships may have contributed to the inconsistency of findings in the literature. The use of more sophisticated statistics that test the possibility of other types of associations between these constructs would allow better testing of more complex relationships.

In summary, it is difficult to answer whether there is a relationship between creativity and mental illness given the various methods and populations that have been studied in pursuit of this question. If a more detailed approach is used to engage this question more systematically, we may finally be able to put this age-old broad question to rest and instead ask more targeted ones.

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DISCLAIMER

The author's expressed opinions do not necessarily reflect those of the Uniformed Services University.

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Advancing the clinical science of creativity

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Can the therapeutic benefits of creativity explain its documented association with psychopathology (Andreasen, 1987; Ludwig, 1995)? Past research seems to have devoted most of its attention to another hypothesis in order to explain this relationship: that features of some disorders may be beneficial for creative cognition (especially in the arts)—for example, the racing thoughts, energy, and openness characteristic of hypomania in bipolar disorder (Johnson et al., 2012), or the rumination observed in depression (Verhaeghen et al., 2005). Other explanations, however, should not be ignored or considered mutually exclusive. Creative work may sometimes exacerbate psychopathology. For example, Kaufman and Baer (2002) suggested that poets may be especially susceptible to mental illness because poetry requires emotional expression and introspection, and unlike prose, may not provide adequate opportunities for making meaning out of one's experience. Conversely, and leaving aside third variable explanations (which also deserve further research), we explore the hypothesis that psychopathology may motivate individuals to engage in creative activities as a way to alleviate their suffering and enhance their well-being. To date, two main empirical literatures have examined this claim. First, reviews of art therapy trials have found that such interventions typically lead to small but statistically significant improvements on a range of psychological measures (Slayton et al., 2010; Forgeard and Eichner, 2014; Maujean et al., 2014). Second, studies examining the benefits of "everyday creativity" suggest that engaging in day-to-day creative activities may both reflect and foster psychological health (Richards, 2007). In keeping with this, findings of a recent experience-sampling study showed that young adult participants were more likely to be engaged in creative activities than other activities when they reported feeling happy and active (Silvia et al., 2014).

In spite of these efforts, important gaps exist in our understanding of the therapeutic benefits of creativity. The first and foremost of these gaps is the following: *to the best of our knowledge, little empirical evidence has demonstrated that creative thinking per se is one of the specific active ingredients accounting for the benefits of creative activities.* To date, past research has investigated the role of other potential mechanisms including adaptive emotion regulation, flow, meaning-making, or growth from adversity in order to explain the benefits of creative activities (Csikszentmihalyi, 1996; Drake and Winner, 2012; Forgeard et al., 2014). Thus, it remains unclear whether the benefits of creative activities are due to creative thinking, or to other factors. We propose that the time is ripe to collect such evidence in order to provide a richer understanding of the nature of the therapeutic benefits of creative thinking. We outline a research agenda to advance the clinical science of creativity from a cognitive-behavioral perspective.

CREATIVE THINKING AS A TRANSDIAGNOSTIC PROCESS

Clinical scientists are developing a growing interest in understanding transdiagnostic processes (i.e., processes shared across disorders) that can account for overlap in symptoms and high rates of comorbidity between psychological disorders, as well as recovery or resilience. These processes (whether pathological or adaptive) can help develop parsimonious theories of disorder and health, as well as pragmatic treatments (Mansell et al., 2009; Forgeard et al., 2011). The research agenda we present here is based on the following hypothesis: Creative thinking constitutes an important yet understudied transdiagnostic process that can be defined, operationalized, assessed, and (if found to be adaptive) enhanced. Creativity refers to *the generation of ideas or products that are both novel (i.e., original, unusual) and useful (i.e., valuable, helpful)* (Stein, 1953; Runco and Jaeger, 2012). Creative thinking can be subjective (i.e., novel and useful to the self) and/or in comparison to others (i.e., novel and useful to all) (Kaufman and Beghetto, 2009). It is also not reserved to prototypical creative domains (e.g., the arts and the sciences), but is present to varying degrees in almost all areas of life—excelling at work, solving thorny interpersonal problems, managing painful emotions, or cooking dinner, are all tasks that may benefit from effective creative thinking. Related to this, creative thinking takes place not only in "creative therapies" (e.g., art therapy), but to some degree also in all forms of psychotherapy.

How does creativity relate to other processes already studied by clinical scientists? Creative thinking is by definition closely related to prospection, defined as the mental representation of possible futures (Seligman et al., 2013). Past research suggests that maladaptive patterns in future-oriented thinking play a key role in psychopathology (Miloyan et al., 2013). For example, both anxious and depressed individuals tend to overestimate future

negative outcomes, and depressed individuals also tend to underestimate future positive outcomes (e.g., MacLeod and Byrne, 1996; Miranda and Mennin, 2007). How might generating novel and useful ideas influence the extent to which individuals think about and prepare for the future in a constructive manner? Creativity may contribute to adaptive prospection by enhancing another closely related process: psychological flexibility, defined as the ability to effectively adapt one's cognitions, emotions, and behaviors to the situation at hand (Kashdan and Rottenberg, 2010). Psychological flexibility does not necessarily require creative thinking—individuals may build a repertoire of options by learning from others or from the environment (as opposed to inventing them anew). We propose, however, that creative thinking probably enhances and strengthens psychological flexibility by allowing individuals to generate new and effective cognitive, emotional, and behavioral strategies on their own. Creative thinking may therefore help counteract a number of detrimental transdiagnostic processes reflecting maladaptive prospection and inflexibility, including repetitive negative thinking, as well as interpretational and expectancy biases (Harvey et al., 2004) by helping individuals adopt adaptive interpretations and coping styles (Fresco et al., 2006).

EXAMINING CREATIVE THINKING AS AN ACTIVE INGREDIENT

What comes next for clinical scientists interested in examining whether and how creative thinking promotes flexibility and decreases psychopathology? Treatment outcome researchers should continue to build empirical support for the efficacy of interventions thought to rely on creative thinking (e.g., art therapy) (Kaplan, 2000; Gilroy, 2006; Maujean et al., 2014). Randomized controlled trials (RCTs) remain the gold standard for this purpose and are necessary to establish that an intervention is empirically supported, among other criteria (Chambless and Hollon, 1998). Of course, preliminary investigations such as single case designs, or uncontrolled trials, often provide useful insights.

Aside from outcome research, rigorous process research is needed in order to test whether creative thinking itself (as opposed, or in addition to, other mechanisms) is one of the active ingredients accounting for positive outcomes. Process research uses appropriate research designs and mediation analyses in order to test causal mechanisms responsible for the effects of an intervention (Kazdin, 2007). In addition to assessing the contribution of creative thinking to outcomes, researchers should also further assess the mediating role of mechanisms examined in prior scholarship (including adaptive emotion regulation, flow, meaning-making, or growth from adversity, as mentioned above), as well as additional mechanisms such as psychological flexibility (Kashdan and Rottenberg, 2010), behavioral activation (Jacobson et al., 2001), or self-efficacy (Bandura, 1997), among others.

Future research should examine the extent to which creative thinking *per se* contributes to these processes, and in turn, to psychological adjustment. Such research is needed to establish whether creative thinking holds special benefits for well-being compared to other thinking styles. This assessment in no way diminishes the value of previous findings, but rather highlights the importance and value of addressing this question in future research. Similarly, little research has investigated whether and how creative thinking abilities contribute to the effects of other forms of therapy. For example, cognitive therapy for depression encourages individuals to generate alternative explanations for automatic thoughts and to assess cognitions for accuracy and usefulness (Beck et al., 1979)—a process which could recruit and/or develop creative thinking abilities.

It is not just on the client's end that creative thinking may enhance outcomes—therapists too need to be creative thinkers. Concerns have been raised about the extent to which manualized treatments can help clients whose symptoms are more complex than those included in RCTs (Westen et al., 2004). Yet, although manuals are required to operationalize and demonstrate the efficacy of a treatment, most researchers and clinicians tend to agree that good manuals leave space for "flexibility within fidelity" in order to effectively tailor treatment to clients' specific concerns and learning styles (Kendall and Beidas, 2007). Therapists' creative thinking abilities therefore probably enable them to flexibly invent new ways to faithfully implement treatments (Deacon, 2000). Within the context of cognitive-behavioral therapy, such creative thinking may be manifested in astute behavioral experiments to test negative cognitions, individualized exposures for anxiety disorders, or compelling metaphors to foster motivation and change (Peterman et al., in press).

CONCLUSION

Researchers interested in advancing the clinical science of creativity have exciting tasks ahead of them: to continue building empirical support for the value of creative therapies using outcome research, and to investigate the role of creative thinking as a transdiagnostic process that may promote adaptive future-thinking and psychological flexibility using process research. These endeavors will enrich our understanding of the relationship between creativity, psychopathology, and health by investigating the circumstances under which creative thinking is or is not beneficial, and by identifying the metacognitive strategies that help individuals tell the difference (Kaufman and Beghetto, 2013). In particular, it is likely that original thinking may only be beneficial in moderate amounts or in certain situations, though more research is needed to test this claim. Related to this, researchers have called for investigating the boundary conditions under which any positive psychological trait or process may become detrimental, as seemingly linear relationships may in fact be nonmonotonic when examining their full range of expression (Grant and Schwartz, 2011). The optimal "dose" of originality and flexibility may therefore vary according to the situation at hand. For example, a person might benefit from considering a wide array of options in order to repair a romantic relationship after a fight. A simple "I am sorry" may not be as effective as an apology expressed in a clever and constructive way. Past a certain point however, the search for novel and flexible solutions may lead to impulsivity or instability (Kashdan and Rottenberg, 2010). In this case, organizing a last-minute unusual and extravagant date or writing an entire book

of poems to apologize could be perceived as "too much of a good thing."

In addition, future research should further examine how various forms of creativity relate to well-being, given that past research in this area has mainly explored the effects of artistic creativity. For example, past research suggests that artists suffer from psychopathology at a greater rate than scientists (Ludwig, 1995). These findings could be influenced by self-selection effects, and/or by the possibility that the creative process has differential benefits for artists vs. scientists. Related to this, the extent to which creative thinking benefits well-being may depend on whether the creative work at hand focuses on one's personal situation or mental state (a case perhaps more typical of the arts) or on an external problem (a case perhaps more typical of the sciences). Thus, future research should further investigate whether and how creative work affects well-being in fields other than the arts.

In light of past research in this area, as well as the promise of addressing existing remaining questions highlighted here, we believe that the study of the therapeutic benefits of creativity will continue to make important contributions to clinical science by further investigating one of the possible causal mechanisms accounting for the relationship between creativity, psychopathology, recovery, and resilience.

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Evolution, creativity, intelligence, and madness: "Here Be Dragons"

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One of the great joys of being a scientist is the hunt for an elusive signal within the noise of data, opinions, biases, and other human foibles associated with the pursuit of knowledge. It is inevitable that this imperfect quest will result in many false starts along the way when looking "through a glass, darkly." Our imperfect and incomplete knowledge of the world must look like an unpolished mirror, reflecting gibberish, at times. However, it also reflects an underlying signal that bears further scrutiny, in spite of our instinct to discard a flawed image of reality. The pursuit of the neural underpinnings of creative cognition is certainly that "dark glass" we peer into so intently, attempting to grasp, through our meager instruments, some hidden truth. Many thinkers and researchers have found that creativity and madness seem somehow to be intertwined, but the signal is weak, the image blurry, and the propensity toward romantic stereotypes is high. And yet, as scientists, we can only follow the data, trying to make sense of what it tells us. So, rather than entertain the premise outright let me take you on a bit of a journey (which will end back at madness, I promise).

First: What if evolutionary processes selected for two types of reasoning? Cosmides and Tooby hypothesized a "dedicated intelligence" that "refers to the ability of a computational system to solve predefined, target set of problems." These problems often involve well established rules—like your mundane life, and Raven's Matrices problems, and acquiring a language (Pinker, 1991). The other problems require "improvisational intelligence" referring to "the ability of a computational system to improvise solutions to novel problems" (Cosmides and Tooby, 2002). These problems are more transient and involve contingencies that may or may not persist over time—like figuring out how to get into your car, having locked your keys inside. Philosophers call the former type of problem solving "deductive reasoning"—the observations necessarily result in a conclusion being made based on the evidence. They are rule based, deterministic, and the cause leads naturally to effect. The latter problem solving is called "abductive reasoning"—there are an infinite number of possible solutions to the myriad challenges faced in the world; therefore a theory best explains the observation, given the evidence. This reasoning is probabilistic, involves approximation, and (importantly) guessing. Both methods are adaptive: one for problems that are familiar, the other for problems that have never been encountered before.

Kanazawa (2004) views intelligence (incorrectly), the pinnacle of deductive reasoning, as THE domain-specific adaptation to solving novel problems in the environment. However, it is my contention that intelligence and creativity occupy two extremes of a dichotomy: intelligence supplies a "dedicated reasoning capacity" for problems that possess rule-based, cause-effect relationships. Others have covered well, and provide empirical support for, the "general purpose problem solving" capacity of intelligence and "g" (Kaufman et al., 2011): I am merely saying here that the mechanism is rather "dedicated" to cause-effect relationships—a capacity with broad applicability to deductive reasoning tasks. In contrast, creativity emerged as an adaptive cognitive mechanism for low frequency, "improvisational reasoning," where solutions to problems are unsighted (Simonton, 2013), and probabilistic approximation could lead to novel solutions. Creative reasoning solves the minority of problems that are unforeseen and yet of high adaptability: "The lightning has struck the tree near the camp and set it on fire. The fire is now spreading to the dry underbrush. What should I do?" (Kanazawa, 2004). In this conceptualization, creativity is an evolved cognitive mechanism to abstract, to synthesize, to solve non-recurrent problems in the environment. Finally, intelligence should be seen as a rather stable evolved mechanism over the last 1.6 million years (i.e., the singular "innovation" being the Acheulean hand ax), while creativity appears to have appeared, in humans at least, in the last ~30,000 years (Gabora and Kaufman, 2010). Intelligence may not be evolutionarily novel, but creativity certainly is.

Perhaps the most parsimonious theory of creative cognition to incorporate evolutionary principles is that of Blind Variation and Selective Retention (BVSR) (Campbell, 1960). Indeed, his theory posits that creativity in humans "represent(s) cumulated inductive achievements, stage by stage expansions of knowledge beyond what could have been *deductively* derived from what had been previously known." Moreover, this creative process possesses three necessary conditions: "a mechanism for introducing variation, a consistent selection

process, and a mechanism for preserving and reproducing the selected variations." Simonton, more recently, assessed and extended BVSR theory, a half-century after its inception, by addressing the shortfalls of Campbell's imprecise definition of what it means for a variation to be "blind:" creativity and discovery are not blind, rather ideas are blind to the extent that the utilities are initially unknown. In contrast, sighted ideas are guided by prior applicable ideas (a.k.a. acquired expertise) (Simonton, 2011). Simonton argues that the "blind variation" component of the theory does not imply that ideas are randomly generated, stating "as long as the probabilities of any generated responses are decoupled from their utilities, the responses are blind without the necessity of being random" (Simonton, 2011). Campbell's notion of BVSR provides an evolutionary framework for creative cognition and has emerged as a "universal selection theory" for numerous other disciplines ranging from neuroscience, to computer science, to philosophy (Simonton, 2010).

Moreover, in Campbell's framework, creative thought represents a simulation or "substitution" of representations of the environment in ones mind, with the "solution" being selected from the numerous thought experiments undertaken, "according to a criterion which is in itself substituting for an external state of affairs." When put into action, the selectively retained solution results in "intelligent behavior" (if adaptive) as opposed to blind floundering. Campbell provides numerous examples of thinkers relying upon "chance combinations" of ideas that appear to coalesce into workable solutions, with Poincaré most famously describing five stages of creative thought (later trimmed to four) including preparation, incubation, illumination, and verification (Poincaré, 1908). All have in common the notion of "trial and error" thinking resulting in an "insight" or "solution" that appears to be most adapted to a given problem in the world. An important implication of the BVSR model is that the results of creative thought are rather disconnected from their antecedents—it is not sufficient to have great minds in order to have creative solutions, just many minds and/or many variations: "insofar as there has been a genuine gain in knowledge, the difference between a hit and a miss lies in the selective conditions thus newly encountered, not in talent differences in the generation of the trials."

Taken one step further, and with Cambell's dichotomy of BVSR in mind, it is not a great leap of imagination to posit that: the "dedicated" cognitive mechanism resides within conscious awareness, with full access to memory stores, planning, attention, and action algorithms serving smooth allocation of resources toward adaptive responses to ongoing, predictable, environmental demands. Measures of such dedicated cognitive mechanisms, termed "IQ" should be (and indeed are) highly correlated with nearly all measures of adaptive ability, including height, health, education, occupation, income, longevity—a staggering array of fitness indicators (Gottfredson, 1997). Stretching our imagination a bit more, we might infer that the improvisational mechanism (unfortunately almost exclusively measures of divergent thinking) will be inconsistently, negatively, and/or weakly correlated with measures of adaptive fitness due to the very low recurrence of such environmental problems (Kanazawa, 2004), the inadequacy of measurement of the underlying cognitive construct (Arden et al., 2010), and the poor correlation between antecedents and their ultimate effective solutions (Simonton, 2014).

In the next step, we can now synthesize the cognitive systems with hypothesized neural mechanisms: the dedicated system is likely to rely upon EXPLICIT or conscious knowledge, while the improvisational system relies more upon IMPLICIT or unconscious knowledge systems (Helie and Sun, 2010). The interaction of explicit and implicit systems can be seen to form the basis of effective, adaptive problem solving within an organism required to solve both common and novel problems in the world. Finally, at a neural network level, the explicit/dedicated system would appear to have significant overlap with the cognitive control network, while the implicit/improvisational system would appear to overlap significantly with the default mode network (Jung et al., 2013).

But what of madness? This is where we really must stretch our thinkers to hypothesize where things might go awry, as they always do, out in the messy world of biological beings. Two competing mechanisms are at play in the human brain, one driving toward abstraction, the other toward certainty. At the far extreme of one end of this highly adaptive bell curve resides psychosis: all things are linked together; all things are related to me; all things are relevant (manifesting as delusions, hallucinations, disorganized speech/behavior). The link between creative genius and psychoticism is not new, having been explored by Eysenck with regard to that rare bird "genius" (Eysenck, 1995). However, true psychosis is a rather rare phenomenon—the lifetime incidence being around 3%, as opposed to "madness" in general (Perälä et al., 2007). At the other extreme is adherence to rigid, rule-based, behavior—the far reaches of which might naturally encompass autism spectrum disorders (ASD's)—also very rare, with a recent total population prevalence found to be 2.64% (Kim et al., 2011). This dichotomy (i.e., psychosis/autism) is not a new hypothesis, having been recently (and brilliantly) applied to "the social brain," (Crespi and Badcock, 2008). Nor is it a radical departure from Carson's "shared vulnerability model," (Carson, 2013) although factors leading to extremes of either creativity (e.g., cognitive flexibility, low latent inhibition) or intelligence (e.g., cognitive closure, high sensitivity) are seen to be pathological in the current model. What is new is to apply this dichotomy to the reasoning brain as manifested through intelligent and creative pursuits (**Figure 1**).

Can one be both "mad" (i.e., overtly psychotic) and creative? Certainly no evidence exists that creative genius (or even garden variety creativity) lurks, emerges, or is unleashed in the presence of overt psychosis (or autism for that matter, savants notwithstanding). Might these examples of "madness" reside at the extreme ends of continua that produced more adaptive levels of flexibility and order (a.k.a. novelty vs. usefulness) (Stein, 1953)? Certainly possible, and increasing evidence suggests this to be so (Nettle, 2006; Glazer, 2009; Kyaga et al., 2011; Fink et al., 2012). Are all of these ideas empirically testable? Indeed, they are—and should be—through falsifiable

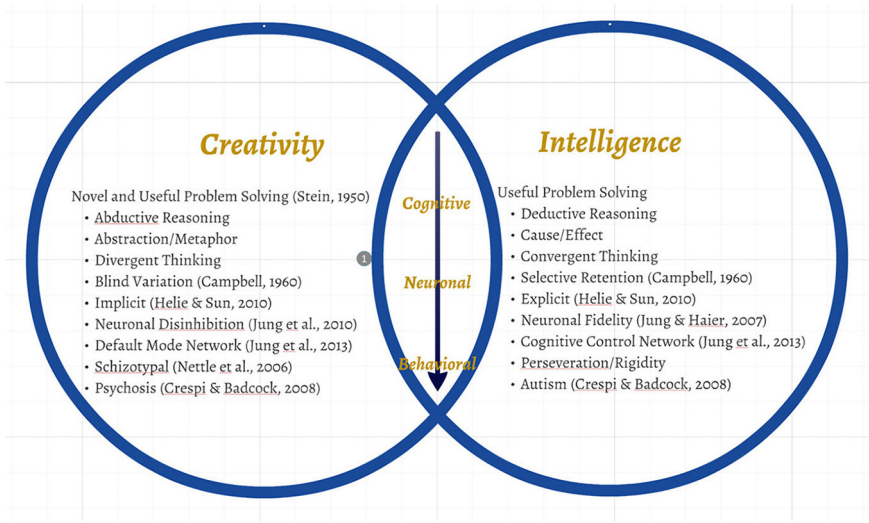

FIGURE 1 | Proposed model for dichotomy of reasoning pressures on human evolution with cognitive, neuronal, and behavioral correlates.

hypotheses as opposed to anecdote, hyperbole, or press release. But beware! When on a scientific journey, looking "through a glass, darkly," one might see all sorts of strange things at the far edges of the known world—some even breathing fire—but shedding little light (Dietrich, 2014).

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Creativity measured by divergent thinking is associated with two axes of autistic characteristics

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Creativity generally involves the conception of original and valuable ideas, and it plays a key role in scientific achievement. Moreover, individuals with autistic spectrum conditions (ASCs) tend to achieve in scientific fields. Recently, it has been proposed that low empathizing and high systemizing characterize individuals with ASCs. Empathizing is the drive to identify the mental status of other individuals and respond to it with an appropriate emotion; systemizing is the drive to analyze a system. It has been proposed that this higher systemizing underlies the scientific achievement of individuals with ASCs, suggesting the possible positive association between creativity and systemizing. However, previous findings on the association between ASCs and creativity were conflicting. Conversely, previous studies have suggested an association between prosocial traits and creativity, indicating the possible association between empathizing and creativity. Here we investigated the association between creativity measured by divergent thinking (CDT) and empathizing, systemizing, and the discrepancy between systemizing and empathizing, which is called *D* score. CDT was measured using the S-A creativity test. The individual degree of empathizing (empathizing quotient, EQ) and that of systemizing (systemizing quotient, SQ), and *D* score was measured via a validated questionnaire (SQ and EQ questionnaires). The results showed that higher CDT was significantly and positively correlated with both the score of EQ and the score of SQ but not with *D* score. These results suggest that CDT is positively associated with one of the characteristics of ASCs (analytical aspects), while exhibiting a negative association with another (lower social aspects). Therefore, the discrepancy between systemizing and empathizing, which is strongly associated with autistic tendency, was not associated with CDT.

Keywords: creativity, divergent thinking, empathizing, systemizing, *D* score, autistic characteristics

INTRODUCTION

The broadly accepted standard definition of creativity is the ability to produce work that is both novel and useful within a certain social context (Stein, 1953; Runco and Jaeger, 2012). As summarized similarly in our previous study (Takeuchi et al., 2013b), creative cognition has been essential to the development of human civilization and plays a crucial role in cultural life. Divergent thinking is defined as the generation and application of several different ideas to solve a given problem (Runco, 1990). It has been proposed as a key aspect of creative cognition (Guilford, 1967), and its strong predictive validity of creative achievement has been identified through meta-analysis (Kim, 2008).

Furthermore, the association between autistic spectrum conditions (ASCs) and scientific achievement is well known (Baron-Cohen, 2003). Recently, it has been proposed that low empathizing and high systemizing characterize ASCs. Empathizing is defined as the drive to identify the mental states of others to predict their behavior and respond with an appropriate emotion (Baron-Cohen et al., 2005). Systemizing is defined as the drive to analyze a system in terms of the rules that govern it to predict its behavior (Baron-Cohen et al., 2005). Moreover, it has been proposed that this higher systemizing underlies the scientific achievement of individuals with ASCs (Baron-Cohen, 2003). However, the results of reports on whether subjects with ASCs show higher or lower creativity measured by divergent thinking (CDT) and other types of creativity are conflicting (Rawlings and Locarnini, 2008; Claridge and McDonald, 2009; Liu et al., 2011). In addition, it is unknown whether CDT is

associated with the two axes of ASCs, empathizing and systemizing, and with the discrepancy between systemizing and empathizing (called *D* score). Related to this point, CDT has been linked to certain prosocial traits, such as extraversion and cooperativeness (Chavez-Eakle et al., 2006; Takeuchi et al., 2013b); in addition, empathizing and prosocial traits are also associated (Nettle, 2007). From the perspective of neuroscience, it has been observed that understanding others (which is a part of empathizing) and self-reflection, have overlapping neural bases in the brain's "default mode" network and overlapping cognitive bases (Saxe et al., 2006; Dimaggio et al., 2008, 2009). On the other hand, CDT, creative cognition, and empathizing have all been associated to the neural mechanisms of the default mode network (Fink et al., 2010, 2012; Takeuchi et al., 2011a,b, 2012a, 2013c, 2014b,c), suggesting the overlap of their neural bases. Considering all of these aspects, we hypothesized that higher empathizing and higher systemizing are both positively associated with CDT.

The purpose of this study was to test the abovementioned hypothesis and to investigate the association between CDT and the traits that are related to ASCs, e.g., empathizing, systemizing, and the discrepancy between systemizing and empathizing, in normal young adults. We further tested whether these associations are affected or mediated by psychometric intelligence. As described above, creative cognition plays several crucial roles in cultural life and in the development of our civilization. Thus, the psychological characteristics of individuals with higher CDT are of public interest.

MATERIALS AND METHODS

SUBJECTS

Data from 895 healthy, right-handed individuals (507 men and 388 women; mean age = 20.82 ± 1.84 years) were used in this study as part of an ongoing project aimed at investigating associations among brain imaging, cognitive functions, aging, genetics, and daily habits (Takeuchi et al., 2010a,b, 2011a,b,c, 2012b, 2013a, 2014a; Taki et al., 2010, 2011). All subjects were university, college, or postgraduate students or those who had graduated from these institutions within 1 year before the experiment and had normal vision. None had a history of neurological or psychiatric illness. A history of psychiatric illnesses and/or recent drug use was assessed using our laboratory's routine questionnaire, in which each subject answered questions relating to their current or previous experiences of any list of illnesses and listed drugs that they had recently taken. Drug screening was performed to confirm that the subjects were not taking any illegal psychostimulants or antipsychotic drugs, which was one of the exclusion criteria used during the course of the recruitment. Subjects with exclusion criteria should have been excluded before they came to the lab, but if they came for some reason, they had to go back once it turned out they had an exclusion criterion. Handedness was evaluated using the Edinburgh Handedness Inventory (Oldfield, 1971). Written informed consent was obtained from each subject in accordance with the World Medical Association (1991). This study was approved by the Ethics Committee of Tohoku University. All experiments were performed at the laboratory.

DIVERGENT THINKING ASSESSMENT

Similar to the case in our previous studies (Takeuchi et al., 2010b,c, 2011a,b, 2012a), the S-A creativity test (Society_For_Creative_Minds, 1969) was used to assess CDT. Guilford (1967) generated the draft plan and supervised the development of the test, after which the test was standardized for Japanese speakers (Society_For_Creative_Minds, 1969).

The test is used to evaluate verbal CDT (Society_For_Creative_Minds, 1969) and involves three types of tasks. Each task is preceded by 2 min of practice involving two questions with a 5-min time limit; thus, in total, the test took 30 min. This test was administered in a group setting. The first task requires subjects to generate unique ways of using typical objects (e.g., "Other than reading, how can we use newspapers?" An example answer is "We can use them to wrap things"). The second task requires subjects to imagine desirable functions of ordinary objects (e.g., "What are the characteristics of a good TV? Write down as many characteristics as possible." An example answer is "A TV can receive broadcasts from all over the world"). The third task requires subjects to imagine the consequences of "unimaginable things" happening (e.g., "What would happen if all the mice in the world disappeared?" An example answer is "The world would become more hygienic"). Each task requires subjects to generate as many answers as possible. The S-A creativity test provides a total score, which was used in this study, as well as scores for the following dimensions of the creative process: (a) Fluency: fluency is measured by the number of relevant responses to questions and is related to the ability to produce and consider several alternatives. Fluency scores are determined by the total number of questions answered after excluding inappropriate responses or responses that are difficult to understand. (b) Flexibility: flexibility is the ability to produce responses from a wide perspective. Flexibility scores are determined by the sum of the (total) number of category types to which the responses are assigned based on a criteria table or an almost equivalent judgment. (c) Originality: originality is the ability to produce ideas that differ from those of others. Originality scoring is based on the sum of idea categories that are weighted based on a criteria table or an almost equivalent judgment. (d) Elaboration: elaboration is the ability to produce detailed ideas (Society_For_Creative_Minds, 1969). Elaboration scores are determined by the sum of responses that are weighted based on a criteria table or an almost equivalent judgment. These four dimensions correspond to the same concepts as those of the Torrance tests of creative thinking (TTCT; Torrance, 1966).

The total score is the sum of the originality score and that of elaboration in the version of the S-A creativity test (Society_For_Creative_Minds, 1969) used here. This is because the Fluency and Flexibility scores are highly correlated with those of Elaboration (Society_For_Creative_Minds, 1969). Scoring of the tests was performed by the Tokyo Shinri Corporation. However, for reference in this study, we also calculated the total score by adding the *z* scores of fluency, flexibility, elaboration, and originality.

The primary analysis was limited to the total score and did not include the score for each dimension because this score was highly correlated with that of the total as well as with each other

(all correlations between the scores of any two dimensions had simple correlation coefficients >0.56). This is consistent with another group of rather similar DT tests (Heausler and Thompson, 1988), TTCT (Torrance, 1966). Heausler and Thompson (1988) concluded that the correlations among the subscales in TTCT were so high that each subscale could not meaningfully provide different information. Treffinger (1985) warned that independent interpretations of TTCT subscores should be avoided. Consistent with this notion, a previous study (Chávez-Eakle et al., 2007) that investigated the association between regional cerebral flow (rCBF) and each dimension revealed that different dimensions were correlated with rCBF in similar regions. Thus, we believe that using only the total score serves the purpose of this study.

Please refer to the appendix of our previous study (Takeuchi et al., 2010b,c) for a sample and the manner in which the tests were scored.

S-A creativity test scores are significantly correlated with various other external measures, such as various personality factors and problem-solving abilities in daily life, suggesting its ability to predict performance in everyday situations (Shimonaka and Nakazato, 2007). Furthermore, S-A creativity test scores are significantly correlated with the frequency of visual hypnagogic experiences, which in turn are correlated with the vividness of mental imagery and neuroticism (Watanabe, 1998). Furthermore, our previous study showed that S-A creativity test scores are positively correlated with extraversion, novelty seeking, motivational state, and daily physical activity level, which are consistent with the findings provided by the other measures of CDT (Takeuchi et al., 2013b).

In short, the points in this subsection were generally as described in our previous studies, which used this measure (Takeuchi et al., 2010b,c, 2011a,b, 2012a, 2013b).

SYSTEMIZING QUOTIENT AND EMPATHIZING QUOTIENT QUESTIONNAIRES

The Japanese version (Wakabayashi et al., 2007) of the systemizing quotient (SQ)/empathizing quotient (EQ) questionnaire (Baron-Cohen et al., 2003; Baron-Cohen and Wheelwright, 2004) was administered to the subjects as in our previous studies (Takeuchi et al., 2013c, 2014b,c). The EQ score was used as an index of empathizing and the SQ score was used as an index of systemizing. This questionnaire consists of 40 items for each quotient and 20 unscored filler items. The scales consist of self-descriptive statements that are scored on a four-point scale ranging from Strongly Disagree to Strongly Agree. Half the items are worded to produce an "Agree" response and the other half a "Disagree" response. Items are randomized to avoid a response bias. Each strong systemizing/empathizing response is awarded two points, each slight systemizing/empathizing response is awarded one point, and the remaining responses are awarded zero points (i.e., each item is scored 2, 1, 0, 0); thus, yielding a range of total scores between 0 and 80 for each quotient.

The following are examples of items included in the SQ–EQ questionnaires:

"I can tune into how someone else feels rapidly and intuitively" (EQ)
"I am good at predicting how someone will feel" (EQ)
"I am fascinated by how machines work" (SQ)
"If I were buying a stereo, I would want to know about its precise technical features" (SQ)

The psychometric properties of the questionnaire are as follows. Some studies have reported that empathizing is largely independent of systemizing, but there is a weak negative correlation between them (e.g., Wheelwright et al., 2006), whereas other studies have failed to find such negative correlations (e.g., Wakabayashi et al., 2007). Individuals with ASCs have higher SQ scores and lower EQ scores than controls (Wakabayashi et al., 2007). Males have higher SQ scores than females, while females have higher EQ scores than males (Wakabayashi et al., 2006b). In addition, students studying humanities have higher EQ scores than those studying sciences, while students studying sciences have higher SQ scores than those studying humanities (Wakabayashi et al., 2006b). Furthermore, actors have higher EQ scores (Nettle, 2006). In addition, EQ is positively correlated with the size of one's social network (Stileman, 2007) and one's performance on a face perception task (Penton-Voak et al., 2007). The autism spectrum quotient (AQ), which is a measure of autistic traits, is well explained by a model that includes both EQ and SQ (Wheelwright et al., 2006). These findings have demonstrated the criterion-related validity of this questionnaire. The internal consistencies of EQ and SQ, which were calculated in a previous study that includes a large sample, were 0.86 and 0.88, respectively; thus, demonstrating the reliability of this questionnaire.

Some researchers may prefer performance-based cognitive measures over questionnaires. However, as far as ASCs are concerned, the validity of this questionnaire is firmly established and this tool is widely used, whereas the performance-based tools that are used to detect ASCs do not tend to work well (Montgomery et al., 2008, 2010). This may be because subjects with ASCs can use strategies and perform at a level that is comparable with that of normal subjects (Frith, 1994).

The D score was calculated as previously described (Goldenfeld et al., 2005). Raw SQ and EQ scores were standardized by subtracting the population mean from the score and then dividing the result by the maximum possible score: $S =$ (raw SQ score – population mean of the raw SQ score)/80 and $E =$ (raw EQ score – population mean of the raw EQ score)/80. For this computation, we used estimated population means (**Table 1**) derived from a large sample ($n = 1250$) of Japanese university students in a previous study (which comprised an almost equal number of males and females; Wakabayashi et al., 2007). The discrepancy between systemizing and empathizing was then quantified as $D = (S - E)/2$. The greater the D score in a positive direction, the stronger one's systemizing is relative to one's empathizing. D scores close to zero represent an equal drive to systemize and empathize. The D score is a measure that is widely used in research by leading experts in relevant areas (Goldenfeld et al., 2005; Wakabayashi et al., 2006b, 2007; Wheelwright et al., 2006; Billington et al., 2007; Lai et al., 2012). The D score is better at distinguishing individuals with ASCs from controls, differentiating typical males and females (Goldenfeld et al., 2005; Wakabayashi et al., 2006b, 2007; Wheelwright et al., 2006), predicting entry into physical sciences and humanities

Table 1 | Mean, SD, and range of psychological variables among men and women.

	Men			Women		
Measure	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Age	20.90	1.94	18 to 27	20.72	1.69	18 to 27
S-A creativity test [official total score (elaboration score + originality score)]	36.26	10.67	7 to 71	38.58	9.78	7 to 68
S-A creativity test (sum of *z* scores of fluency, flexibility, elaboration and originality)	−0.29	3.75	−12.22 to 10.65	0.37	3.34	−11.02 to 10.51
Empathizing	29.46	9.58	9 to 66	34.31	9.85	12 to 63
Systemizing	27.98	8.75	6 to 56	21.49	7.41	8 to 54
D score	0.0577	0.0712	−0.1519 to 0.2981	−0.0132	0.0719	−0.2206 to 0.1919

(Wakabayashi et al., 2006b; Billington et al., 2007; Focquaert et al., 2007), and predicting programming aptitude (Wray, 2007) compared with the EQ or SQ score. However, because the *D* score has components of both *S* and *E*, examining the correlates of the *D* score alone does not reveal the whole picture. Thus, we also investigated the correlates of *E* and *S* scores. One of the problems of using the difference between two values is that when the difference is calculated, the determination of the source of the variations of the value is not possible (DeGutis et al., 2013). However, in the present study, the difference in the SDs of EQ and SQ scores was not substantial (See **Table 1**). Furthermore, *z* scores of EQ and SQ scores can be used to calculate the *D* score (Wakabayashi et al., 2007), which can control for differences in the SDs of EQ and SQ scores. However, we used the present method to calculate the *D* score partly because it is more widely used (Baron-Cohen, 2003; Baron-Cohen et al., 2005; Goldenfeld et al., 2005; Wakabayashi et al., 2006a; Auyeung et al., 2009) and partly because the distribution of the *D* score calculated using the *z* scores of EQ and SQ is very similar to that calculated using the present method and it produced similar imaging findings (Lai et al., 2012).

Briefly, this subsection's points were generally as described in our previous studies, using this measure (Takeuchi et al., 2013c, 2014b,c).

ASSESSMENT OF PSYCHOMETRIC MEASURES OF GENERAL INTELLIGENCE

Raven's Advanced Progressive Matrix is one of the purest psychometric measures of general intelligence (Raven, 1998) and is often shown to be best correlated with general intelligence. Because this is the best general intelligence measure (Raven, 1998), it was used to assess intelligence. This test was used in our study to adjust for the effect of individual psychometric measures of intelligence on the psychological variables involved in this study's hypothesis. Raven's Advanced Progressive Matrix (Raven, 1998) contains 36 non-verbal items requiring fluid reasoning ability. Each item consists of a 3 × 3 matrix with a missing piece to be completed by selecting the best of eight alternatives. The score of this test (number of correct answers in 30 min) was used as an index of individual psychometric measure of intelligence. It was administered to determine if adjusting the effects of general intelligence alters the association between empathizing, systemizing, *D* score, and CDT.

STATISTICAL ANALYSES

The relationships among psychological variables were investigated using multiple regression analyses and the PASW statistical software (version 18 for Windows; SPSS Inc., Chicago, IL, USA).

We investigated the associations between CDT (S-A creativity test scores) and the other psychological variables described above after correcting for the effects of age and sex. Each multiple regression analysis investigated the associations between the S-A creativity test score and one of the following: EQ score, SQ score, and *D* score after correcting for the effects of age and sex (meaning that each analysis included three covariates). Therefore, we performed three multiple regression analyses. In addition, we investigated these associations after correcting for the effects of age, sex, and the Raven's Advanced Progressive Matrix score (meaning that each analysis included four covariates).

In all analyses, results with a threshold of $P < 0.05$, which were corrected for false discovery rate (FDR) using the two-stage sharpened method (Benjamini et al., 2006), were considered statistically significant. The correction for multiple comparisons using this method was applied to the results of the abovementioned three multiple regression analyses. FDR is the error rate in the set of comparisons that are called significant, i.e., the proportion of comparisons that are wrongly called significant. In other words, among the multiple tested results, 5% of the results that are determined to be significant using this method are not truly significant. In FDR testing, if there is truly no signal anywhere in the tested results, an FDR-controlling method has the same control as a family wise error correction. FDR-based methods are more powerful and sensitive compared with the other approaches available for multiple statistical testing (see Benjamini and Hochberg, 1995 for a full discussion; Genovese et al., 2002). We also conducted the entire analyses again, using the sum of the *z* scores for the four dimensions (fluency, flexibility, originality, and elaboration) of the S-A creativity test, instead of the official total score

of the S-A creativity test (sum of the scores for elaboration and originality).

RESULTS

BASIC DATA

Table 1 shows the average ± standard deviation (SD) values for age and scores for each psychological variable. EQ and SQ scores significantly negatively correlated (simple regression analysis; $P = 0.011$, $t = 2.550$, $r = 0.085$).

ASSOCIATIONS BETWEEN PERFORMANCE ON THE DIVERGENT THINKING TEST AND PSYCHOLOGICAL VARIABLES

We investigated the association between performance of DT (S-A creativity test score) and empathizing, systemizing, and the discrepancy between these two parameters through multiple regression analyses.

A higher S-A creativity test score was significantly and positively correlated with EQ and SQ scores but not with the *D* score. The significance and insignificance of the results were unaltered by using the sum of the *z* scores for the four dimensions (fluency, flexibility, originality, and elaboration) of the S-A creativity test, instead of the official total score of the S-A creativity test (sum of the scores of elaboration and originality). The significance and insignificance of the results were not altered by the inclusion of the score on Raven's Advanced Progressive Matrix as a covariate. For the results of all statistical analyses, please refer to **Table 2**.

DISCUSSION

This study investigated the associations between CDT and empathizing, systemizing, and the discrepancy between systemizing and empathizing using a large sample of normal young adults and validated psychological measures. Consistent with our hypothesis, we demonstrated that higher CDT was associated with higher systemizing, which is one of the psychological characteristics of ASCs. However, another major psychological characteristic of ASCs (lower empathizing) was associated with lower CDT. As a result, the discrepancy between systemizing and empathizing was not associated with CDT, despite the large size of our sample. These associations were unaffected by inclusion of the psychometric measures of intelligence as a covariate in the analysis model.

The present result of an association between higher empathizing and higher CDT is congruent with previous studies that reported an association between prosocial traits and higher CDT. To the best of our knowledge, this is the first time that a higher CDT score was associated with higher empathizing (drive to identify the mental states of others in order to predict their behavior and respond with an appropriate emotion, Baron-Cohen et al., 2005). The association was congruent with our previous reports on associations between other higher prosocial traits, such as higher extraversion as well as higher cooperativeness and higher CDT (Chavez-Eakle et al., 2006; Takeuchi et al., 2013b). Furthermore, a higher CDT score was previously associated with higher social skills (interpersonal emotional intelligence), which is also congruent with the present finding. Thus, the present finding, together with previous studies, supports the idea that individuals with higher CDT exhibit prosocial traits. The reasons for the association between CDT and these traits are unclear; it may be partly ascribed to the fact that both depend on widespread brain connectivity or functional properties of the network involved in social cognition (default mode network; Takeuchi et al., 2010c, 2012a, 2013c, 2014b). However, these are speculations and future studies may need to investigate the details of these associations.

This study's results might provide insight into problem solving in the everyday lives of individuals with ASCs. In this study, CDT was positively associated with empathizing. Furthermore, CDT is associated with the ability to solve problems in everyday life (Shimonaka and Nakazato, 2007), and individuals with ASCs have deficits solving these problems despite higher systemizing, which is apparently likely to contribute to problem solving (Baron-Cohen, 2003). There could be numerous sources for this deficit, including empathizing and dysexecutive problems in individuals with ASCs. But perhaps, given the present results, lowered CDT due to lower empathizing might be one source of such deficits and indirectly hinder the adaptivity of individuals with ASCs.

The present results suggest that autistic tendency is not associated with CDT, because empathizing and systemizing positively contributed to CDT. To the best of our knowledge, this is the first time that a higher CDT score was associated not only with higher empathizing but also with higher systemizing. By analyzing the system, subjects with higher systemizing may be

Table 2 | Statistical values from the multiple regression analyses of associations between S-A creativity test scores and cognitive variables with the covariates of age and sex.

Variables	*N*	uncorrected *P* values	FDR-adjusted *P* values	*t* value	Standardized partial regression coefficient (β)	Simple correlation coefficients (Pearson's *r*)*
Empathizing	895	$4.51*10^{-5}$, $3.85*10^{-4}$	$4.73*10^{-5}$, $4.00*10^{-4}$	4.100, 3.564	0.142, 0.124	0.168, 0.147
Systemizing	895	$1.54*10^{-4}$, $2.19*10^{-3}$	$8.09*10^{-5}$, $1.15*10^{-3}$	3.800, 3.073	0.135, 0.110	0.081, 0.065
D score	895	0.492, 0.446	0.1722, 0.1561	−0.687, −0.763	−0.026, −0.028	−0.076, −0.069

The left values are statistical results of analyses using the official total score of S-A creativity test (elaboration score + originality score). The right values are statistical results of analyses using the sum of z scores of fluency, flexibility, elaboration and originality.

**Note other statistical values are those of multiple regression analyses but simple correlation coefficients are those from simple regression analyses.*

able to generate effective ideas better. The effect sizes appeared to be equal. Low empathizing and high systemizing are two essential components that are considered to characterize ASCs (Baron-Cohen, 2004). The higher systemizing observed in individuals with ASCs has been suggested to underlie the scientific achievement of these individuals (Baron-Cohen, 2004). However, findings of an association between ASCs and CDT are not consistent and remain elusive, as described in the Section "Introduction." The present results suggest that at least one of the reasons for the lack of a robust association between ASCs and CDT is the fact that while higher systemizing contributes to higher CDT, lower empathizing works in the opposite manner, and there are no effects of the association between ASCs (which is very highly predicted by the *D* score, Wheelwright et al., 2006) and CDT.

In this research, we measured empathizing and systemizing through questionnaires, believing them to be the method developed by leading experts on autism (Baron-Cohen, 2003). As for ASCs, perforamnce-based measures are known for their pitfalls because subjects with apparent dysfunctions do not manifest poorer performance than others (Montgomery et al., 2008, 2010), possibly due to the subjects developing alternative strategies (Frith, 1994). Nonetheless, questionnaire-based measures of cognition are also historically known for their pitfalls. For example, the correlation between the performance-based measures for the emotion-related competence and the questionnaire-based measures for emotion-related competence are moderate (for example, in the case of ability emotion intelligence and trait emotion intelligence $r = 0.46$; Bar-On, 2000). Moreover, while performance-based measures tend to correlate with general intelligence (Lam and Kirby, 2002), questionnaire-based measures tend to correlate with other questionnaire-based measures as well (Gardner and Qualter, 2009). In other words, performance-based measures and questionnaire-based measures reveal different psychological characteristics. Particularly, in severe brain injuries or neuronal degenerations, subjects lack insight into their symptoms or show deficits in metacognition (Prigatano, 1991), and this deficit is associated with other clinical problems (Lysaker et al., 2008, 2010, 2011). Although, in non-clinical subjects, this situation may be less of an issue. For example, in the evaluation of dysexecutive symptoms through questionnaires, in clinical samples, others estimate dysexecutive symptoms more severely than the subjects themselves; conversely, in non-clinical samples, subjects estimate their problems more severely (Burgess et al., 1998). This suggests that only among clinical samples do subjects underestimate the severity of their dysexecutive problems. In particular, patients with schizophrenia are known for their deficits in the core components of empathy (Derntl et al., 2009). On the other hand, patients with schizophrenia are also known for their deficits in metacognition and self-reflection (Dimaggio et al., 2009). In fact, self-reflection and understanding others' minds are partly overlapping (as well as distinct) cognitive and neural bases (Saxe et al., 2006; Dimaggio et al., 2008). Possibly then, some normal adults with severe deficits in insight into themselves may have simultaneous deficits in empathetic competence, but do not notice. Thus, in the future, it would be perfect if we could evaluate empathetic competence (or systemizing, too) through semistructured interviews (Lysaker et al., 2002), performance-based measures using audiovisual stimuli, and online social interactions in order to obtain higher ecological validity in real life (Dziobek, 2012), too. Another possibility is by performing evaluations from close acquaintances, along with self-reported questionnaires. Particularly, in related investigations among subjects with severe neuronal injuries or neuronal degenerations, who are likely to have substantial deficits in metacognition and insight into their conditions, the nature of the evaluations used should be carefully considered.

There was at least another limitation to this study, which was common to our previous studies and other studies that use college cohorts (Song et al., 2008; Jung et al., 2010; Takeuchi et al., 2010b,c, 2011b; Wei et al., 2013). As previously described (Takeuchi et al., 2012a), we used young healthy subjects with high educational backgrounds. Limited sampling of the full range of intellectual abilities is a common hazard when sampling from college cohorts (Jung et al., 2010). Whether our findings would also hold across the full range of population samples and a normal distribution must be determined using larger and more representative samples. Focusing on highly intellectual subjects was certainly warranted for the purpose of this study, given the association between higher intelligence and higher CDT among subjects with normal and inferior intelligence (Sternberg, 2005). In addition, similar to our previous studies of CDT, we only used the verbal DT test as a measure of DT. Thus, our interpretation may have certain limitations in terms of generalization regarding this aspect as well, although a previous study that used both verbal and figural DT tests showed that the psychological characteristics of both tasks in terms of the association with personality traits are quite similar (Chavez-Eakle et al., 2006).

Creative cognition is important in our cultural and everyday life. Our findings showed that higher systemizing, which is one of the major characteristics of ASCs, was associated with higher CDT, whereas lower empathizing, which is another characteristic of ASCs, was associated with lower CDT. Therefore, the discrepancy between systemizing and empathizing, which is strongly associated with autistic tendency, was not associated with CDT.

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Creativity and psychopathology: are there similar mental processes involved in creativity and in psychosis-proneness?

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The putative link between creativity and psychopathology is nearly as legendary and mysterious as the long-standing view from antique mythology according to which eminent creative achievements were perceived as the result of a "higher power," mostly caused by inspiration by muses. In fact, there are many illustrative examples of creative people who suffer(ed) from serious mental disorders, leading some authors to the notion that "... madness may be the price for possessing one of the most sublime human gifts" (Barrantes-Vidal, 2004, p. 59). Within the scientific domain, literature reviews came to quite different conclusions, assuming no, only a weak or even a strong association between creativity and psychopathology (Barrantes-Vidal, 2014, p. 170), ranking this topic into the most controversially discussed issues in the field of creativity. Nevertheless, there appears to be some consensus that at least less severe manifestations of psychopathology are associated with creativity (e.g., Barrantes-Vidal, 2004; Claridge and Blakey, 2009; Nelson and Rawlings, 2010). As we will briefly indicate in the following, especially people who are prone to psychosis (characterized in its most severe manifestation by e.g., delusions, hallucinations, disorganized thought, negative symptoms; see e.g., Heckers et al., 2013, for a review of the domains of psychopathology that define psychosis) have been found to show elevated levels of creativity.

CREATIVITY AND PSYCHOSIS-PRONENESS

According to Carson (2011) empirical evidence for an association between creativity and psychopathology can be found from the latter half of the last century onward, stimulated by two separate studies. Heston (1966) investigated the psycho-social adjustment of children of mothers with schizophrenia relative to matched control subjects and he reported that the former were "notably successful adults" (p. 819), as they possessed artistic talents and showed imaginative adaptations to life. Some years later, Karlsson (1970) reported that relatives of psychotic patients (schizophrenics, manic depressives) had a higher rate of listing in Who is Who, both based on a general listing and on creative endeavors. Since then, researchers began to examine the incidence of psychopathology in highly successful, creative achievers. As one of the landmark studies in this field, Andreasen (1987) for instance found a higher rate of mood disorders (involving bipolar disorder) in prominent writers as compared to a matched control group. Most interestingly, there was also a higher prevalence of mood disorders and creativity in the first-degree relatives of the writers as compared to the relatives of the control subjects, suggesting that the "mad genius" trait might be genetically heritable (Andreasen, 1987). Recent epidemiological studies with large sample sizes confirm the association between professional authors and psychiatric disorders, especially schizophrenia and bipolar disorder, and indicate a familial association between overall creative professions for schizophrenia, bipolar disorder, anorexia nervosa, and possibly autism (Kyaga et al., 2011, 2013).

The idea that at least some facets of psychopathology could be associated with creativity has also received some support from the psychometric research tradition. Eysenck's (1995) psychoticism (P) dimension for instance, a personality trait involving cold, un-empathic, aggressive, and impulsive behavior, has been observed as being substantially associated with various creativity-related demands, particularly with the originality facet of creativity (Abraham et al., 2005; Fink et al., 2012; for review see Acar and Runco, 2012). Eysenck's P dimension is thought to underlie a variety of psychotic disorders (Eysenck, 1995; but see also Chapman et al., 1994) and it "...differs from psychosis by not being pathological and hence enabling people to use remote associations in a constructive way (Eysenck, 1995, p. 244). While individuals scoring low on P are characterized by e.g., conformity or conventionality, high P scorers show traits such as impulsivity, aggression or hostility, and therefore a high tendency toward unconformity, which could possibly provide some explanation for the observed relationship between originality and psychoticism.

Creativity has also been investigated in relation to schizotypy, which involves traits such as unusual experiences, cognitive disorganization, introvertive anhedonia (lack of enjoyment/interpersonal domain) or impulsive non-conformity (Claridge and Blakey, 2009), and is known as increased vulnerability of developing psychotic disorders (e.g., Claridge, 1997; Fisher et al., 2004; Nettle, 2006). Studies yielded evidence that some facets of schizotypy (positive symptoms such as unusual, hallucinatory experiences) may be linked to psychometrically determined creativity (e.g., Claridge and Blakey, 2009). Similarly, the studies of Nettle (2006) and Nelson and Rawlings (2010) found elevated levels of positive schizotypy in a sample of artists. In light of such findings, it has been argued that some cognitive styles may be similar between creative and psychotic thinking (Keefe and Magaro, 1980; Eysenck, 1995; Carson, 2011). Such common cognitive processes can be assumed in "overinclusiveness" of thinking (Eysenck, 1995) or reduced latent inhibition which might both enable that more stimuli (also such that are not directly task-relevant) enter conscious awareness and may thus people allow to "... perceive and describe what remains hidden from the view of others" (Carson et al., 2003, p. 499; for a detailed discussion on these processes see Eysenck, 1995; Carson, 2011). In using functional magnetic resonance imaging, Fink et al. (2014) showed that originality and schizotypy were associated with similar functional brain activity patterns during creative ideation, which also adds some evidence to the idea that similar mental processes may be implicated in creativity as well as in psychosis-proneness. Quite similarly, Jung et al. (2010) investigated white matter integrity (assessed by Fractional Anisotropy, FA) in a sample of young healthy volunteers and they found that lower levels of FA within left inferior white matter (especially the anterior thalamic radiation) were associated with higher divergent thinking performance. Jung et al. (2010) refer to studies involving schizophrenic and bipolar patients which likewise found reduced FA in similar brain regions (Sussmann et al., 2009), demonstrating potential overlap between the neural substrates of both creative cognition and psychopathology or psychosis.

CREATIVITY AND ADAPTIVE TRAITS

It seems that some mental processes might be quite similar between creative and psychotic thinking, but current literature does not allow for strong conclusions, not least due to severe methodological and conceptual challenges in this field (Schlesinger, 2009; Dietrich, 2014; Simonton, 2014). Importantly, research from the psychological research tradition also provides evidence that creativity is amongst others closely associated with intelligence (Jauk et al., 2013), domain-specific knowledge/expertise (e.g., Weisberg, 1999), motivation (Collins and Amabile, 1999), and thus with highly adaptive traits (see also Simonton, 2000). In addition, the burgeoning field of neuroscience studies on creativity reveals that this ability is associated with "ordinary" (rather than psychopathological) brain processes that are likewise seen in various cognitive ability domains (e.g., Fink and Benedek, 2014). And finally, creativity involves various "positive" personality traits such as openness, broad interests or self-confidence (Barron and Harrington, 1981; Feist, 1998).

A particular conceptual challenge in this field is that any association of creative cognition/divergent thinking with psychosis-proneness often implicates disorganization of thought and impaired cognitive control, which may facilitate the loosening of constraints and conventional ways of thinking, and thus the generation of more distant, unusual or novel associations. At first sight, however, this appears to be at odds with a large amount of empirical evidence on a positive relationship between creativity (in terms of divergent thinking ability) and intelligence (Kim, 2005; Nusbaum and Silvia, 2011; Jauk et al., 2013, 2014), and highly effective executive functioning (e.g., working memory and cognitive inhibition; Benedek et al., 2012, 2014), rather indicating a crucial role of cognitive control in creative thought.

CREATIVITY—A CONTROLLED EXPLOSION OF MIND

So, on the basis of the reviewed studies, what are we to conclude about the putative link between creativity and psychopathology? Carson (2011) assumes that high levels of intelligence and working memory capacity act as "protective factors" in the sense that they facilitate more efficient processing of available information produced by "vulnerability factors" such as novelty seeking or reduced latent inhibition. Similar to that idea, both higher and lower levels of cognitive control may be implicated in creativity, but at different stages of the creative process (cf. Kris' supposition of primary vs. secondary process cognition in creative individuals; Kris, 1952). The disposition for the generation of unusual representations may be particularly conducive to creative thought, if these representations can be organized and elaborated effectively. This point can be further illustrated by invoking the Geneplore model (Finke et al., 1992), which distinguishes between generation and exploration phases during creative idea generation, where the latter phase is concerned with the exploration, elaboration, and evaluation of initially generated mental representations. Within this framework, some psychopathological traits may generally be thought to feed the generation stage, while at the exploration stage high cognitive control is needed to separate the wheat from the chaff, and to elaborate relevant unusual representations toward actually creative ideas (cf. Kaufman and Paul, 2014).

Merten and Fischer (1999) provide interesting evidence in favor of this assumption. They compared the association behavior of creative people (professional writers and actors) to individuals suffering from schizophrenia and normal controls. They found that, given the instruction to be original, the creative group showed highly original response behavior, similar or even more original than that of individuals with schizophrenia. However, when instructed to generate common associations, the creative group performed similar to the control group, while the schizophrenic group still showed higher unusualness. Finally, the creative group was also better able to assess the commonness of their responses than individuals with schizophrenia. These findings demonstrate that creative people show a similar disposition for the generation of novelty like individuals suffering from schizophrenia, but they also show better control of their ideational output, including the

evaluation of appropriateness of their responses.

The Merten and Fischer (1999) study also points to a potentially important methodological issue in the psychometric study of creativity and psychopathology. According to common definitions (Runco and Jaeger, 2012), novelty is a central ingredient of creativity, because common ideas can never be considered as creative. However, the second necessary criterion is the appropriateness or the efficacy of an idea, which in turn determines whether an idea or a product is actually creative or just absurd. It may thus well be the case that studies using divergent thinking tasks (i.e., common indicators of creative cognitive potential) will likely fail to observe the complete picture of differences when simply scoring for ideational fluency or uniqueness, as these scores disregard the creative quality of ideas. Unfortunately, such coarse scorings of divergent thinking tasks are still quite common, sometimes justified by an apparent lack of discriminant validity of the scores derived from subjective scoring methods. However, methods for the efficient scoring of the creative quality of ideas independent of the confounding influence of fluency are readily available (Silvia et al., 2008; Benedek et al., 2013).

We hence assume that available evidence for a relationship of psychosis-proneness with creativity, particularly within the psychometric research tradition, may sometimes be restricted to unusualness. But any trait supporting the generation of unusual representations may be highly conducive for the creativity of thought, if it concurs with the necessary cognitive control to guide evaluation and elaboration at the exploration stage of creative idea generation (see also Carson, 2011; Kaufman and Paul, 2014). We would thus more likely succeed in our understanding of the putative link between creativity and psychopathology if we base our conclusions more strongly on carefully designed empirical studies, which focus on specific cognitive and neural processes that may be similar or even shared between creative and psychotic thinking. This would require the application of well-proven methods and paradigms in carefully selected samples of both clinical and non-clinical samples of participants. In this context, researchers also need to carefully distinguish between different creativity domains (e.g., artistic vs. scientific), given that creative people in different domains show different personality profiles (Feist, 1998), and given the affinity of psychosis-proneness to the artistic creativity domain (Nettle, 2006; Nelson and Rawlings, 2010; Kyaga et al., 2011, 2013). Taken together, such an approach could identify some of the complex cognitive and neural processes involved in both creativity and psychopathology, and would have the potential to draw a more concise picture of some mechanisms overlapping between both constructs, rather than linking creativity generally to "madness."

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On the interrelation between reduced lateralization, schizotypy, and creativity

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Genius and madness have long been thought to be intimately entwined. However, the idea remains controversial: some rail against the stereotype of the mad scientist or the crazy artist (e.g., Schlesinger, 2009, 2012), while others note higher incidences of mental illness amongst creative geniuses, including prize-winning authors, visual artists, and poets (e.g., Andreasen, 1987; Kaufman, 2000-2001; Nettle, 2006). Consistent with early ideas of a shared genetic basis (e.g., Lombroso, 1891; Galton, 1892), a growing body of research highlights a positive correlation between mental illness and heightened creativity (e.g., Rothenberg, 2001). The relationship between creativity and schizotypy warrants close examination, as greater creativity is associated with higher levels of schizotypal traits (e.g., Folley and Park, 2005). Atypical brain lateralization may play the causal role, being evident in people who are highly creative *and* in people who have high levels of schizotypal traits (e.g., Weinstein and Graves, 2002). This paper argues in favor of the opinion that atypical lateralization prompts a cognitive processing style that enhances both creativity and schizotypy, suggesting a potential biological foundation for the link between genius and madness.

SCHIZOTYPY AND CREATIVITY

Conceptually, schizotypy represents the presence of schizophrenic-like thought patterns and/or belief systems in the absence of psychosis, including traits such as magical thinking, unusual perceptual experiences, and paranormal beliefs (American Psychiatric Association, 2013). Such traits index highly with a variety of unusual behaviors, prompting others to describe the schizotypal personality as "odd" or "eccentric" (Fisher et al., 2004). Although schizotypy is associated with vulnerability to schizophrenia (Lenzenweger, 2011), it is also linked with enhanced creativity: people involved in creative professions, such as musicians and visual artists, gain higher scores on measures of schizotypy than those in non-creative professions (Brod, 1997; Schuldberg, 2000–2001; Preti and Vellante, 2007; Gibson et al., 2009). Similarly, people with normal but high levels of schizotypal traits gain higher scores on a variety of measures of creativity, including conceptual expansion (drawing animals that reside on another planet), creative imagery (inventing and assembling an object from 3-dimensional figures; e.g., Abraham and Windmann, 2008), and the Torrance Tests of Creative Thinking (10 performance subtests that assess both verbal and nonverbal creative thinking; Poreh et al., 1994; see Thys et al., 2014, for review of the creativity assessment tools used to assess the relationship between creativity and psychopathology). Such findings index a close relationship between schizotypal traits, such as magical thinking and unusual perceptual experiences, and creative thinking.

SCHIZOTYPY AND COGNITIVE STYLE

Given that novelty forms a key component of creativity, an ability to think "outside the box" is a valuable characteristic of the creative mind. Whereas a wildly unconstrained, loosely-associated thinking style has a maladaptive manifestation in the disordered thinking symptomatic of schizophrenia, a moderate tendency toward linking remotely-associated concepts appears evolutionarily advantageous in that it promotes creative thinking. This may help explain the link between high levels of schizotypal traits and enhanced creativity: whereas disordered thinking in schizophrenia is beyond the individual's control, people with normal but high levels of schizotypal traits retain a greater degree of control over their cognitive processes (e.g., Lenzenweger, 2011). Thus, in schizotypy, the propensity to link remotely-associated concepts may serve to enhance creativity.

In assessing creativity, psychological research often relies on measures of divergent thinking, measuring "creativity" itself appearing too broad, too subjective, and perhaps simply ineffable. Divergent thinking is a flexible, open, and associative thinking style beneficial in solving complex problems and generating novel associations. Measures of divergent thinking confirm that people with normal but high levels of schizotypal traits show enhanced divergent thinking (e.g., Green and Williams, 1999), indicating superior ability in generating novel associations. This ability to draw connections between elements that initially appear to have nothing in common (Simonov, 1997) represents a fundamental component of creativity. In terms of semantic representation, it appears likely to result from "flatter" association hierarchies (i.e., more and broader associations to a stimulus); such hierarchies generate more creative solutions because they facilitate the drawing together of a wide range of information to solve a problem. In contrast,

because "steeper" association hierarchies (i.e., fewer, more common associations to a stimulus; Grabner et al., 2007) are more focussed, activating a narrow range of the most common associations, they are less conducive to creative generation.

Research confirms that people with high levels of schizotypal traits activate flatter association hierarchies, allowing them to draw connections between distantly-related semantic associates. For example, people with higher magical ideation scores (a core component of measures of schizotypy) judge unrelated words to be more closely related than people with lower magical ideation scores (Mohr et al., 2001), suggesting facility in linking unrelated ideas. Gianotti et al. (2001) reported similar findings, indicating that people who believe in paranormal phenomena produce more original word associations than skeptics, suggesting looser semantic associations and a greater ability to link unrelated ideas (see also Pizzagalli et al., 2001). As heightened schizotypy is a predictor of increased paranormal belief (Hergovich et al., 2008), such findings appear highly consistent. The tendency to make links between unrelated or distantly-related concepts contrasts with the conceptual boundaries that typify "normal" thinking, but characterizes both schizotypal and creative thinking. Schizotypy and creativity are also linked by atypical cerebral lateralization, suggesting a potential causal link.

LATERALITY, SCHIZOTYPY, AND CREATIVITY

The brains of people with schizophrenia evidence both structural and functional atypicalities, showing reduced hemispheric lateralization in comparison with healthy controls (see Lindell, 2011). Consistent with the proposed continuum between normal functioning and schizophrenia, with schizotypy representing "the less deviant bedfellow of 'schizophrenia'" (Claridge, 1997, p. 3), people with high levels of schizotypal traits also show evidence of reduced (e.g., Suzuki and Usher, 2009) or reversed (e.g., Rawlings and Claridge, 1984) hemispheric asymmetry. For example, Somers et al.'s (2009) meta-analysis of 10,058 participants found that higher levels of schizotypy were associated with increased incidence of non-right-handedness (particularly mixed handedness), indexing reduced lateralization. Dichotic listening data appear congruent, with people with high levels of schizotypal traits showing an atypical left ear (i.e., right hemisphere) advantage for dichotic listening (Poreh et al., 1994). Such findings imply greater than normal involvement of the right hemisphere in schizotypal individuals, consistent with research demonstrating a significant association between heightened creativity, schizotypy, and greater reliance on the right hemisphere (e.g., Weinstein and Graves, 2002). Atypical lateralization and greater involvement of the right hemisphere may help explain the heightened creativity associated with schizotypy.

The associational hierarchies described by Grabner et al. (2007) neatly match the semantic representational systems of the left and right hemispheres, being "steep" and "flat" respectively. Whereas activation in the left hemisphere spreads in a focussed manner, consistent with a more narrow, focussed semantic network and a steep associational hierarchy, activation in the right hemisphere spreads in a broader, more diffuse way, potentially facilitating links between distant associations in a flat associational hierarchy (e.g., Chiarello et al., 1990). Consequently, priming the left hemisphere with an ambiguous word (e.g., bank, scales) prompts activation of only the dominant meaning (e.g., money, weight); in contrast, priming the right hemisphere activates both dominant and subordinate associations (e.g., river, fish) (Burgess and Simpson, 1988).

Leonhard and Brugger (1998) argue that the right hemisphere's broad semantic representations play a causal role in creative and/or schizotypal thought processes; Folley and Park's (2005) functional imaging data are congruent. Folley and Park found that people with both high creativity (divergent thinking) and high levels of schizotypal traits preferentially recruited the right prefrontal cortex, contrasting with activation patterns observed in participants with schizophrenia and healthy controls. As the prefrontal cortex appears involved in processing novelty, such a finding appears entirely logical. Moreover, it implies that the ability to draw links between remotely associated concepts engages right hemisphere processes, consistent with the proposed diffuse semantic network in that hemisphere. Recent functional imaging data offer further support, highlighting a link between diffuse allocation of attention and heightened creativity (Takeuchi et al., 2011; Benedek et al., 2014). Overall, reduced hemispheric lateralization and diffuse attentional allocation appear beneficial for creativity, and indeed, are likely to play a causal role in the heightened creativity evident in people with high levels of schizotypal traits. A less lateralised brain may allow greater interhemispheric communication and transfer, facilitating the flat associational hierarchy that allows the drawing together of disparate concepts that promotes creative thinking (Lindell, 2011).

CAVEAT

This opinion paper has argued that lateralization, schizotypy, and creativity are causally related, citing evidence of atypical hemispheric asymmetry in people with high levels of schizotypy and creativity (e.g., Weinstein and Graves, 2002; Folley and Park, 2005). However, it should be noted that findings in this literature are mixed, with some studies reporting no relationship between lateralization and schizotypy (e.g., Gooding and Braun, 2004). Inconsistencies in finding may be attributable to various factors, including differences in the measures used to assess schizotypy, the behavioral task(s) implemented, and the gender splits of the samples tested (see Schofield and Mohr, 2014, for discussion). Indeed, Schofield and Mohr's (2014) within-subjects investigation demonstrated that different schizotypy questionnaires produce inconsistent associations with behavioral measures of lateralization. Differences in finding may also arise from differences in the levels of schizotypal traits in the populations tested. Studies testing a schizotypy sample at the higher end of the normal spectrum may be more likely to report atypical lateralization than studies testing samples with schizotypy scores at the lower end of the range.

Methodological differences also contribute to inconsistencies in finding, as highlighted in Badzakova-Trajkov et al.'s (2011) study. Their functional imaging data indicated no correlation between

magical ideation (a key component of measures of schizotypy) and hemispheric asymmetry; in marked contrast, their behavioral investigation found a negative correlation between magical ideation and handedness strength, indicating higher levels of schizotypal traits in mixed handers. This lack of consistency between functional imaging and behavioral findings highlights the need for further investigation, particularly as few studies have used imaging techniques to assess lateralization in people with normal but high schizotypy scores. Imaging investigations have instead focussed on clinical populations, assessing lateralization in people diagnosed with schizophrenia or schizotypal personality disorder. As investigations in the normal population have predominantly relied on behavioral techniques (e.g., visual half-field) and indirect measures of lateralization (e.g., handedness), there is a pressing need for structural and functional imaging investigation. Until such research is conducted, the proposed relationship between atypical lateralization, schizotypy, and creativity must be considered speculative.

CONCLUSIONS

In the years since Leonhard and Brugger (1998) proposed that altered lateralization underlies both enhanced creativity and heightened schizotypy, the supporting data have grown. Schizotypy, creativity, and laterality appear intimately related, implying a common, presumably genetic, underlying mechanism. A cognitive bias toward broad processing, and drawing links between disparate concepts and apparently unrelated ideas, appears central to both the traits of schizotypy (e.g., magical ideation, perceptual abberations) and superior performance on measures of creativity (e.g., divergent thinking); this cognitive bias appears to reflect predominant right hemisphere processing.

At present there is a relative dearth of research assessing schizotypal traits, creativity, and right hemisphere activation/processing within the same population. Instead, the majority of the research has measured only two members of the triumvirate (e.g., schizotypy and creativity, or creativity and right hemisphere activation), allowing only speculative inferences about the interrelation of the three to be drawn. Simultaneous comparison of measures of all three components in the same population is needed to allow firmer conclusions.

Whilst the data imply a robust association between reduced lateralization, schizotypy, and creativity, the causal mechanism is presently unresolved. Genetic investigations presumably hold the key. For example, Mayseless et al. (2013) demonstrated a link between the dopaminergic system and creativity, with divergent thinking ability associated with polymorphism of the gene coding for DRD4 (dopamine receptor). Genome-wide investigations similarly show great promise, with Smalley et al. (2005) confirming genetic linkage between the regions coding for atypical cerebral asymmetry and disorders including autism, implying a shared phenotype. Similar genome-wide investigation is needed to investigate the presence of regions of linkage overlap in the genes for schizotypy, creativity, and atypical lateralization, potentially offering biological support for the proposed link between creative genius and madness.

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Frontal lobe neurology and the creative mind

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Concepts from cognitive neuroscience strongly suggest that the prefrontal cortex (PFC) plays a crucial role in the cognitive functions necessary for creative thinking. Functional imaging studies have repeatedly demonstrated the involvement of PFC in creativity tasks. Patient studies have demonstrated that frontal damage due to focal lesions or neurodegenerative diseases are associated with impairments in various creativity tasks. However, against all odds, a series of clinical observations has reported the facilitation of artistic production in patients with neurodegenerative diseases affecting PFC, such as frontotemporal dementia (FTD). An exacerbation of creativity in frontal diseases would challenge neuroimaging findings in controls and patients, as well as the theoretical role of prefrontal functions in creativity processes. To explore this paradox, we reported the history of a FTD patient who exhibited the emergence of visual artistic productions during the course of the disease. The patient produced a large amount of drawings, which have been evaluated by a group of professional artists who were blind to the diagnosis. We also reviewed the published clinical cases reporting a change in the artistic abilities in patients with neurological diseases. We attempted to reconcile these clinical observations to previous experimental findings by addressing several questions raised by our review. For instance, to what extent can the cognitive, conative, and affective changes following frontal damage explain changes in artistic abilities? Does artistic exacerbation truly reflect increased creative capacities? These considerations could help to clarify the place of creativity—as it has been defined and explored by cognitive neuroscience—in artistic creation and may provide leads for future lesion studies.

Keywords: creativity, prefrontal cortex, frontotemporal dementia, artistic, divergent thinking

Beyond its cultural, aesthetic or artistic aspects, creativity can be defined from a neuroscientific perspective as "the ability to produce a work that is both original (new, unusual, novel, unexpected) and valuable (useful, good, adaptive, appropriate)" (Sternberg and Lubart, 1999; Dietrich, 2004). Creative thinking usually involves the ability to break with conventional well-established ideas and to develop alternative behaviors in new and unexpected situations. In this sense, creativity may be considered to be a particular form of adaptation or problem solving (Runco, 2004; Sternberg, 2006). In this theoretical view, creativity relies on fundamental cognitive processes such as working memory, attention, planning, cognitive flexibility, mentalizing, and abstract thinking (Carlsson et al., 2000; Dietrich, 2004; Bogousslavsky, 2005; Changeux, 2005). These functions depend largely on the integrity of the prefrontal cortex (PFC), a brain region that is essential for behavioral adaptation and highly integrated mental functions. Functional neuroimaging data in healthy subjects also show that the PFC plays an important role in the cognitive processes involved in creativity (Gonen-Yaacovi et al., 2013). Therefore, both cognitive theories and neuroimaging data suggest that the integrity of the PFC is essential for creative thinking, and that neurological diseases that damage PFC regions (or their connections) would affect cognitive creativity processes. Some experimental studies have indeed demonstrated the impairment of creativity after prefrontal damage (Rankin et al., 2007; de Souza et al., 2010; Shamay-Tsoory et al., 2011; Abraham et al., 2012).

However, in contrast with these theories and experiments, a series of clinical observations reports the facilitation of artistic abilities in some patients with neurodegenerative disease affecting the frontal lobes, raising the question of a possible increased creativity following frontal damage (Palmiero et al., 2012; Schott, 2012; Gretton and ffytche, 2014). An exacerbation of creativity in neurological diseases affecting the frontal lobes would question the role of the PFC in creativity.

Herein, we propose that cognitive aspects of creativity depend on the integrity of PFC subregions and we hypothesize that some of these contradictory data may be reconciled by considering the repercussion of frontal symptoms into the patients' production,

by taking into account affective and conative aspects of creativity, and by comparing the artistic and neuroscientific perspectives of creativity. This discussion will be illustrated using a clinical case of artistic production during the course of the behavioral variant frontotemporal dementia (bvFTD).

PREFRONTAL FUNCTIONS AND CREATIVITY

The PFC is highly developed in humans and plays a crucial role in elaborating and controlling voluntary and goal-directed behaviors, expanding behavior far beyond the sole repertoire of automatic and reflexive actions. The PFC enables adaptive behavior according to one's own objectives and to the context while taking into account past experiences and needs (Goldman-Rakic, 1995; Shallice and Burgess, 1996; Fuster et al., 2000; Miller and Cohen, 2001; Levy and Volle, 2009; Volle et al., 2013). This central role in adaptive behavior is supported by intense connections between the PFC and other brain regions (Dubois et al., 1995; Mesulam, 1998). The strong connective properties of this region suggest that the PFC is involved in integrating or combining different types of information according to the task goal. The PFC is connected with the sensory systems involved in perception, enabling access to information about the current environment. The PFC receives information about past events and knowledge though connections to long-term memory circuits. The PFC is also part of the limbic system and receives information on the individual needs, emotions, and motivations (Schoenbaum et al., 2009; Fellows, 2013) to guide decisions. The PFC interacts with motor systems that program, perform and monitor the plan of actions (Catani and Thiebaut de Schotten, 2012; Yeterian et al., 2012; Cole et al., 2013; Rojkova et al., under revision). Thus, the PFC can be considered to be a convergence hub that enables the integration of different types of information and the formation of mental representations of both the external and inner worlds (Ramnani and Owen, 2004; Reynolds et al., 2006; Nee et al., 2013) that can guide more sophisticated patterns of behavior.

Furthermore, the connections between the PFC and other brain regions are usually reciprocal, enabling the PFC to exert control over other brain systems, in addition to receiving information. For instance, control signals over the action system may inhibit actions that would not be suitable in a given context, and control over perceptual systems enables the selection of relevant information in the environment (Picton et al., 2007; Levy and Wagner, 2011; Volle et al., 2012). The supervisory role of the PFC also allows the selection and the voluntary retrieval of information in memory (Martin and Cheng, 2006; Thompson-Schill and Botvinick, 2006; Badre and Wagner, 2007; Strenziok et al., 2013). Several recent models describe a hierarchical postero-anterior organization of the control functions that are exerted by PFC in which an increased control requirement for behavioral adaptation recruits more anterior PFC subregions (Koechlin et al., 2003; Koechlin and Hyafil, 2007; Azuar et al., 2014). Other models also describe a posteroanterior PFC gradient in the abstraction degree of the mental representations that can be formed; more anterior regions support more abstract thinking (Christoff et al., 2001, 2009; Badre and Wagner, 2007; Volle et al., 2010).

Overall, the PFC enables the formation and control of mental representations according to an internal goal by selecting information from the environment or from memory, by forming or selecting rules, and by resisting spontaneous prepotent responses (Levy and Volle, 2009). These prefrontal properties are assumed to support creativity as well as complex human abilities such as planning, reasoning, problem solving, abstract thinking (Carlsson et al., 2000; Godefroy, 2003; Dietrich, 2004; Bogousslavsky, 2005; Changeux, 2005; Burgess et al., 2009; Levy and Volle, 2009). In other words, our knowledge of PFC structure and functions supports the assumption that the PFC is essential for cognitive processes that underlie creative thinking. Experimental studies using creativity tasks in healthy participants and in patients confirm this hypothesis.

EXPERIMENTAL STUDIES ON THE NEURAL CORRELATES OF CREATIVITY

FUNCTIONAL NEUROIMAGING APPROACH: A ROLE FOR THE FPC IN CREATIVITY

Functional imaging studies have attempted to explore the cerebral bases of creativity processes using various experimental tasks (see Arden et al., 2010; Dietrich and Kanso, 2010; Jung, 2013 for reviews). Some studies relied on ecological tasks attempting to imitate creativity in real life, but most of them employed tasks drawn from theoretical cognitive models. Studies with a more ecological approach used tasks such as story writing (Bechtereva et al., 2004; Howard-Jones et al., 2005; Shah et al., 2013), object design (Kowatari et al., 2009; Ellamil et al., 2012), or music improvisation (Bengtsson et al., 2007; Berkowitz and Ansari, 2008; Limb and Braun, 2008; de Manzano and Ullen, 2012).

Among the studies based on theory-based creativity tasks, the most frequent framework used to examine the brain correlates of creativity was the divergent thinking approach (Runco and Acar, 2012). Divergent thinking tests typically require generating the maximal number of new or unusual responses. One of the classical divergent thinking tasks is the *Alternate Uses task*, which assesses the ability to produce many alternative uses of a common object such as a brick.

Another approach, which was proposed by Mednick (Mednick, 1962; Mednick et al., 1964), considers that creativity results from "the forming of associative elements into new combinations, which either meet specified requirements or are in some way useful. The more mutually remote the elements of the new combination, the more creative the process or solution." One experimental task to test this hypothesis is to present three unrelated words without obvious connections between them (e.g., stain, glass, and red), and to ask the subject to find a fourth word that is related to each of these words (e.g., wine) (Jung-Beeman et al., 2004; Kounios et al., 2006). This task has been mainly used to investigate the phenomenon of "insight" or "Aha!" or "Eureka" (Kounios et al., 2006). "Aha" describes a subjective experience that occurs when solving a problem for which the solution suddenly comes to mind without effort or difficulty and is associated with a feeling of pleasure and confidence (Luo et al., 2004; Aziz-Zadeh et al., 2009; Qiu et al., 2010; Tian et al., 2011). This "Aha" experience is the cornerstone of another approach in creativity studies, that of problem solving with insight. Problems that raise an insight phenomenon include statements with strong implicit constraints that guide the

search for a solution in the incorrect direction. The solution to these problems requires breaking these constraints and implicit associations and opening the search space to more possibilities. According to the classical model from Wallas (Kozbelt, 2011), this element is part of a creative process that follows four stages. Insight follows a preparation and an incubation phases and is followed by a verification phase. For many authors, the creative process is not this linear but instead alternates between phases of idea generation, evaluation, and the selection of ideas (Changeux, 2005; Simonton, 2010; Ward and Kolomyts, 2010; Ellamil et al., 2012).

A recent coordinate-based meta-analysis (Gonen-Yaacovi et al., 2013) using GingerALE free software (Eickhoff et al., 2012; http:www.brainmap.org/ale/) reviewed the published data regarding the investigation of the neural basis of creative thinking in functional neuroimaging studies. This study included 34 articles reporting 44 different experiments that employed the different creative paradigms aforementioned, i.e., divergent thinking tasks (Seger et al., 2000; Howard-Jones et al., 2005; Asari et al., 2008; Fink et al., 2009, 2010; Chrysikou and Thompson-Schill, 2011; Abraham et al., 2012; Ellamil et al., 2012; Kröger et al., 2012; Rutter et al., 2012) combination tasks and problem solving (Jung-Beeman et al., 2004; Luo et al., 2004; Geake and Hansen, 2005; Vartanian and Goel, 2005; Kounios et al., 2006; Mashal et al., 2007; Siebörger et al., 2007; Aziz-Zadeh et al., 2009; Qiu et al., 2010; Tian et al., 2011; Aziz-Zadeh et al., 2012; Cardillo et al., 2012; Green et al., 2012; Huang et al., 2013), as well as ecological tasks attempting to capture real life creativity instead of hypothesized cognitive processes (Bechtereva et al., 2004; Howard-Jones et al., 2005; Bengtsson et al., 2007; Berkowitz and Ansari, 2008; Limb and Braun, 2008; Kowatari et al., 2009; Ellamil et al., 2012; de Manzano and Ullen, 2012; Shah et al., 2013).

Despite the diversity of tasks used in these studies, the results showed a common set of brain regions as the neural basis of creative thinking, including multiple areas within the PFC and regions involved in semantic memory (the temporo-parietal region and posterior temporal and antero-lateral temporal cortex).

Additionally, this meta-analysis showed that distinct prefrontal subregions support distinct cognitive creativity processing. More specifically, tasks based on divergent thinking (to imagine alternative uses of objects or new designs) and those requiring the combination of information (to compose a sentence with unrelated words or to combine different figures to produce a new one, e.g.) were associated with both common and distinct prefrontal areas. Caudal lateral PFC was involved in both task categories, while more anterior PFC areas appear to be more task-oriented. For instance, within the frontal pole, the lateral part was more related to combination tasks, while its medial portion was engaged in divergent thinking tasks.

Together, these findings underlie the importance of PFC in creativity and suggest that different processes involved in creative thinking rely on distinct subregions within the PFC, in particular along the posterior-anterior axis and the medial-lateral axis. If PFC subregions are involved in creativity tasks, as suggested by functional imaging, one expects that damage to these areas would provoke impairment in the same tasks.

EXPERIMENTAL PATIENT STUDIES: DECREASED CREATIVITY AFTER PREFRONTAL DAMAGE

Whether PFC regions are critical to creativity has been explored in very few patient studies. Creative thinking has been studied in patients with focal brain lesions (Shamay-Tsoory et al., 2011; Abraham et al., 2012) and in one of the most frequent causes of frontal damage: frontotemporal dementia (FTD) (Rankin et al., 2007; de Souza et al., 2010). FTD is a neurodegenerative disease and the second most common cause of dementia in patients under 65 years of age. FTD encompasses three different clinical syndromes: the behavioral variant (bvFTD) and the language variants, i.e., progressive non-fluent aphasia and semantic dementia (SD).

de Souza et al. (2010) investigated creativity in patients with bvFTD, using a standardized test of divergent thinking, the Torrance Test of Creative Thinking (TTCT; Torrance, 2004). The TTCT includes both verbal and figurative tasks. TTCT establishes objective criteria to measure creative production, by scoring three main aspects: (1) the fluency, i.e., the total number of responses, (2) the flexibility, i.e., the number of different categories to which the responses belong, and (3) originality, which is the number of new responses, here considered as responses that are statistically infrequent. Fluency and flexibility are usually defined as executive functions and are classically assessed in neuropsychological testing. The results from de Souza and colleagues showed that bvFTD patients performed worse than controls (a normal and a pathological control group) in all dimensions of the TTCT (fluency, flexibility, and originality) for both figurative and verbal tasks. bvFTD patients had also impaired performance in frontal functions such as flexibility, inhibition, abstraction and planning. These findings are consistent with previous data demonstrating that bvFTD patients have impairments in the production of new ideas either in an ecological task of artistic drawing or on the TTCT (Rankin et al., 2007). This study also showed that behavioral disorders such as perseverations and behavioral disinhibition (often sexual) could partly account for the "originality" of frontal patients in their responses in TTCT. In other words, some of the production features may be considered to be manifestations of the behavioral disorders that characterize bvFTD; these were not observed in the control subjects.

In this study, brain correlates of creative abilities were also explored in bvFTD patients, and perfusion in prefrontal regions measured using SPECT correlated with creativity performance at the TTCT (de Souza et al., 2010). More interestingly, there was a clear concordance among the regions reported in this study and those observed in functional neuroimaging studies in healthy subjects (Gonen-Yaacovi et al., 2013), in particular in the left inferior frontal gyrus [BA 47], the left posterior inferior and middle temporal gyri [BA 37], the left inferior parietal lobule [BA39/40], and the left precuneus [BA 23].

Focal prefrontal lesions also impact creative thinking, as demonstrated by two recent lesion studies that examined the consequences of focal brain damage (such as stroke) on creative performance (Shamay-Tsoory et al., 2011; Abraham et al., 2012). Shamay-Tsoory et al. (2011) compared patients' performance on the TTCT according to distinct lesion locations: frontal pole, posterior part of the PFC, or outside the PFC. The results showed that

damage to the frontal pole was specifically associated with a deficit at the TTCT. More especially, the originality criterion was the most compromised, and patients with damage to the frontal pole were less original in their response than other patients. Abraham et al. (2012) used several creativity tests in patients with various lesion locations and showed that patients with lateral frontal damage were impaired in both fluency and originality aspects of divergent thinking tasks.

Taken together, these data supports the critical role of PFC in creative thinking. From a cognitive perspective, cerebral findings from patient studies agree with functional neuroimaging results (Carlsson et al., 2000; Seger et al., 2000; Bechtereva et al., 2004; Jung-Beeman et al., 2004; Goel and Vartanian, 2005; Howard-Jones et al., 2005; Asari et al., 2008; Aziz-Zadeh et al., 2009; Fink et al., 2009, 2010; Kowatari et al., 2009). These findings are also consistent with studies that used SPECT (Chavez-Eakle et al., 2007), voxel-based morphometry (Jung et al., 2010b; Takeuchi et al., 2010a; Gansler et al., 2011), and diffusion tensor imaging (Jung et al., 2010a; Takeuchi et al., 2010b).

However, against all odds, a series of medical observations have reported the facilitation of artistic abilities in patients with damage to the frontal lobes (Palmiero et al., 2012; Schott, 2012).

CLINICAL OBSERVATIONS OF CREATIVITY IN NEUROLOGICAL PATIENTS

The description of patients developing artistic abilities raises the question of enhanced creativity following frontal damage, which would challenge the neuroimaging findings in controls and patients and the theoretical role of prefrontal functions in creativity processing. To better understand the relationships between frontal damage, frontal functions, artistic ability, and creativity, we performed a mini-review of published articles reporting changes in artistic production by neurological patients.

A MINI-REVIEW OF MEDICAL REPORTS ON CREATIVITY

We actively searched the *PubMed database* for previous medical reports of changes in artistic skills in neurological patients. Unlike experimental studies on creativity that were usually based on various experimental tasks using objective measures and more instructed tasks, these clinical reports were based on a subjective evaluation of spontaneous patients' productions in the artistic domain. We used the following key-words terms: "dementia, frontotemporal+dementia, Alzheimer's+disease, semantic+dementia, or stroke" AND "creativity, artistry, or artist." We looked for articles published until March 2014. We also included articles cited in previous reviews on creativity in patients (Palmiero et al., 2012; Schott, 2012; Gretton and ffytche, 2014). We did not include Parkinson disease, as artistic facilitation in this condition may most likely relate to the dopa medication rather than to the brain damage itself (Lhommee et al., 2014). The papers found throughout this research were evaluated for relevance and duplicate cases were excluded.

We found 35 relevant papers reporting the degradation, emergence, preservation or improvement of creative expression in 53 patients after the onset of different neurological diseases (see **Table 1**): 19 patients with temporal variant FTD (semantic dementia), 10 patients with behavioral variant FTD, eight patients with Alzheimer's disease, four patients with primary progressive non-fluent aphasia, and 12 patients with various neurological diseases (Espinel, 1996; Miller et al., 1998, 2000; Crutch et al., 2001; Thomas-Anterion et al., 2002, 2010; Kleiner-Fisman et al., 2003; Mell et al., 2003; Mendez and Perryman, 2003; Annoni et al., 2005; Fornazzari, 2005; Lythgoe et al., 2005; Serrano et al., 2005; Chatterjee et al., 2006; Drago et al., 2006a,b; Budrys et al., 2007; Finney and Heilman, 2007; Midorikawa et al., 2008; Seeley et al., 2008; Liu et al., 2009; Thomas-Anterion, 2009; Chakravarty, 2011; Chatterjee et al., 2011; van Buren et al., 2013; Galarza et al., 2014; Takahata et al., 2014). All reported patients with temporal FTD ($n = 19$) presented the emergence ($n = 11$), increase ($n = 2$), or preservation ($n = 6$) of creative production but no degradation of artistic abilities (Miller et al., 1996, 1998; Edwards-Lee et al., 1997; Drago et al., 2006b; Wu et al., 2013). Most case reports on behavioral variant FTD ($n = 10$) noted the emergence ($n = 4$), increase ($n = 4$), or preservation ($n = 1$) of artistic abilities (Miller et al., 1998; Thomas-Anterion et al., 2002; Mendez and Perryman, 2003; Serrano et al., 2005; Liu et al., 2009; Thomas-Anterion, 2009). The effects of Alzheimer's disease on artistic production were more heterogeneous, with observations of both increase (Fornazzari, 2005; Chakravarty, 2011) and degradation (Cummings and Zarit, 1987; Crutch et al., 2001; Serrano et al., 2005; van Buren et al., 2013). Other neurological degenerative diseases or strokes of various locations were associated with heterogeneous profiles (Annoni et al., 2005; Lythgoe et al., 2005; Thomas-Anterion et al., 2010; Takahata et al., 2014). The cognitive, behavioral, and artistic changes reported in the reviewed studies are synthetized in **Table 2**.

This non-systematic review highlights that some FTD patients develop enhanced artistic abilities and suggests that the relations between FTD, frontal functions, artistic abilities and creativity are unclear, as discussed below. We first would like to illustrate the paradoxical relationship between frontal symptoms and creativity by reporting the clinical observation of a patient who developed artistic abilities during the course of bvFTD. This is a new clinical case (unpublished original data) that will be discussed in conjunction with the other reviewed findings.

CLINICAL VIGNETTE

Mrs. YCFZ (case number 963564), a retired dentist secretary aged 83 years, was evaluated in October 2010 in the Cognitive and Behavioral Neurology Unit of the Clinics Hospital from the Federal University of Minas Gerais (Belo Horizonte, Brazil). She was referred to the unit for the evaluation of behavioral and cognitive symptoms that had been evolving for approximately 2 years. Her preceding medical history was unremarkable, except for systemic hypertension, which was well controlled.

The family reported that the patient demonstrated striking behavioral changes. She was progressively uninterested in previously appreciated household chores, and she narrowed her usual cooking repertoire, abandoning the preparation of traditional dishes from her native country, El Salvador. Increased appetite manifested as a troublesome binge eating cookies. Additionally, the patient became progressively less concerned with personal grooming. The patient developed a new stereotyped and fixed routine. For example, she started to eat one banana every day at

Table 1 | Synthesis of published articles reporting changes in artistic creativity in neurological patients.

Author and year	Diagnosis	Neuroimaging data	Change in abilities	Previous interest in Art?	Art domain	Neuropsychological data
Miller et al., 1998, 2000 (Pt 3)	Frontal FTD	SPECT: bifrontal and temporal hypoperfusion (right > left)	E	Occasionally produced novels (not a professional)	Photo	MMSE = 26/30 Preserved language and constructions Impaired executive tests (WCST, Stroop, TMT) Behavioral disinhibition and compulsions
Thomas-Anterion et al., 2002 and Thomas-Anterion, 2009	Frontal FTD	CT scan: frontotemporal atrophy SPECT: frontal hypoperfusion	E	No	Drawing	Language and memory impairment Impaired executive tests Emotional difficulties Apathy Stereotypies
Mendez and Perryman, 2003 (Pt 1)	Frontal FTD	MRI: frontotemporalatrophy PET-FDG: Bifrontal and right temporal hypometabolism	I	Yes (professional graphic artist)	Drawing	MMSE = 22/30 Preserved language, face processing and visuospatial tests Decreased verbal fluency Concrete interpretation of proverbs Compulsions and hoarding Poor insight
Mendez and Perryman, 2003 (Pt 2)	Frontal FTD	MRI: normal SPECT: Bifrontal and right temporal hypoperfusion	I	Yes (professional photographer and graphic designer)	Drawing	MMSE = 23/30 Preserved visuospatial and face processing tests Decreased verbal fluency, executive functions and memory Difficulties with proverbs Inappropriate social behaviors and compulsions Loss of insight
Mendez and Perryman, 2003 (Pt 3)	Frontal FTD	MRI: frontotemporal atrophy SPECT: Frontal and right anterior temporal hypoperfusion	I	Occasionally caricatures (not a professional)	Drawing	MMSE 20/30 Preserved visuospatial and face processing tests Decreased verbal fluency and memory Difficulties with similarities and proverbs Poor insight Compulsions Disinhibited behaviors, impulsivity
Mendez and Perryman, 2003 (Pt 4)	Frontal FTD	MRI: frontotemporal atrophy SPECT: Bifrontal and bitemporal hypoperfusion	P	Yes (professional artist)	Not specified	MMSE 23/30 Preserved visuospatial and face processing tests Decreased verbal fluency Good proverb interpretation Disinhibition of personal behavior Compulsive behaviors
Serrano et al., 2005 (Pt 3)	Frontal FTD	MRI: normal SPECT: Left fronto-temporoparietal hypoperfusion	I	Yes (painter)	Painting	Impaired language skills Impaired executive tests (TMT, spans) Preserved performance on similarity test Compulsive behaviors

(Continued)

Table 1 | Continued

Author and year	Diagnosis	Neuroimaging data	Change in abilities	Previous interest in Art?	Art domain	Neuropsychological data
Liu et al., 2009	Frontal FTD (a)	MRI: atrophy in bilateral anterior and left lateral frontal regions.	E	No	Painting Sculpture	MMSE 28/30 Preserved visuospatial skills Impaired executive tests Abstraction difficulties Lack of emotion, empathy and insight Impaired verbal memory and semantic Antisocial and compulsive behaviors Paintings contain sexual disinhibition Obsessions about art and dots and stripes
Thomas-Anterion, 2009 (Pt 2)	Frontal FTD	No imaging data	E	No	Drawing Poetry	No neuropsychological data Obsession about art
Budrys et al., 2007	Frontal FTD (b)	MRI: bilateral frontotemporal atrophy	D	Yes (professional artist)	Painting	MMSE 25/30 Aphasia and amnesia Difficulties on abstract reasoning Verbal and writing perseverations
Edwards-Lee et al., 1997 (Pt LTLV 1) and Miller et al., 2000	Temporal FTD	MRI: bitemporal atrophy, SPECT: Bitemporal hypoperfusion	P	Yes (pianist)	Music	MMSE = 1/30 Preserved attentional and visuospatial skills Impaired executive tests (Stroop, TMT) Compulsive behaviors
Edwards-Lee et al., 1997 (Pt LTLV 3) and Miller et al., 2000	Temporal FTD	MRI: left temporal lobe atrophy SPECT: Left temporal hypoperfusion	P	Yes	"Artistic skills"	MMSE 26/30 Preserved visuospatial skills Semantic anomia Memory impairment
Edwards-Lee et al., 1997 (Pt LTLV 5) and Miller et al., 2000	Temporal FTD	MRI: generalized atrophy SPECT: Bitemporal hypoperfusion	E	No	Painting	MMSE = 15/30 Preserved visuospatial skills Executive tests markedly impaired (TMT, Stroop, verbal fluency) Anomic aphasia and impaired memory
Miller et al., 1998 and 2000	Temporal FTD (c)	SPECT: bitemporal (Left > right) and mild left frontal hypoperfusion	E	No	Painting drawing	MMSE = 16/30 Preserved visuospatial skills Letter fluency = 2 Perseverations on executive tests Disinhibition and compulsive behavior
Miller et al., 1998	Temporal FTD	No imaging data	E	No	Painting	No neuropsychological data Disinhibition in language.
Miller et al., 1998 and 2000	Temporal FTD	MRI: bifrontal and left temporal atrophy SPECT: Left frontal and bitemporal hypoperfusion	I	Yes	Sculpture	MMSE = 9/30 Mild deficit in visuospatial tests Decreased verbal fluency Impaired memory and naming Disinhibition and compulsive behavior

(Continued)

Table 1 | Continued

Author and year	Diagnosis	Neuroimaging data	Change in abilities	Previous interest in Art?	Art domain	Neuropsychological data
Miller et al., 1998 and 1998 (also in Miller et al., 1996 and Edwards-Lee et al., 1997 Patient RTLV 4)	Temporal FTD	MRI: bitemporal atrophy SPECT: Bilateral temporal hypoperfusion	E	No	Painting	MMSE = 15/30 Fluent verbal output, with semantic anomia Letter fluency = 2 Disinhibition and compulsive behavior
Midorikawa et al., 2008 (Pt 1)	Temporal FTD	MRI: left temporal atrophy	E	No	Painting	Language deficits (semantic deficits) Abnormal behaviors (intrusiveness, repetitive actions)
Midorikawa et al., 2008 (Pt 2)	Temporal FTD	MRI: left temporal atrophy	E	No	Painting	Language deficits (semantic deficits)
Miller et al., 2000 (Pt 1)	Temporal FTD	SPECT: bitemporal, left greater than right, hypoperfusion with frontal sparing	P	Yes (previous inventor)	Inventor	MMSE = 21/30 Boston naming test: 1/60 Normal on Rey Complex Figure Disinhibited behavior
Miller et al., 2000 (Pt 2)	Temporal FTD	MRI: focal left temporal atrophy SPECT: bitemporal, left greater than right, hypoperfusion with frontal sparing	P	Yes (previous bridge)	Bridge	MMSE = 25/30 Normal on Wisconsin Card Sort Test Normal visual reproduction abilities Intact social skills
Miller et al., 2000 (Pt 3)	Temporal FTD	SPECT: bitemporal hypoperfusion with frontal sparing	P	Yes (previous inventor)	Inventor	MMSE = 22/30 Boston naming test: 16/60 Apathy
Miller et al., 2000 (Pt 4)	Temporal FTD	SPECT: bitemporal, left greater than right, hypoperfusion with frontal sparing	E	No	Music	MMSE = 17/30 Boston naming test: 4/60 Normal visual reproduction abilities Personality changes (childlike, euphoric) Compulsive behavior
Miller et al., 2000 (Pt 5)	Temporal FTD	SPECT: moderate left temporal and mild left frontal hypoperfusion	E	No	Music	MMSE = 25/30 Decreased verbal output
Miller et al., 2000 (Pt 6)	Temporal FTD	Positron emission tomography showed left anterior hypometabolism	P	Yes (music)	Music	MMSE = 15/30 Fluent speech with perseverations
Drago et al., 2006a	Temporal FTD	MRI: anterior bitemporal atrophy	I	Yes (visual artist)	Painting	Preserved visuospatial skills Language deficits Behavioral disorders (more impulsive and belligerent)
Wu et al., 2013 (Pt 1)	Temporal FTD	MRI: bilateral (left greater than right) anterior temporal atrophy extending to hippocampal and orbitofrontal regions	E	No	Verbal (poetry)	MMSE 26/30 Normal performance on visual memory and visuospatial function Impairment in verbal memory Preserved executive function Disinhibition

(Continued)

Table 1 | Continued

Author and year	Diagnosis	Neuroimaging data	Change in abilities	Previous interest in Art?	Art domain	Neuropsychological data
Wu et al., 2013 (Pt 2)	Temporal FTD	MRI: atrophy in (left greater than right) anterior temporal lobe atrophy	E	No	Verbal (rhyming)	MMSE 30/30 Marked anomia, with intact comprehension and repetition Impairment in executive functions and in visual memory Preserved short-term verbal memory
Wu et al., 2013 (Pt 3)	Temporal FTD	MRI: marked atrophy in the anterior temporal lobes and amygdala, right greater than left, with moderate atrophy of the orbitofrontal cortex, right anterior insula, and right parahippocampus	E	No	Verbal (writer)	MMSE 28/30 Poor performance on tasks of semantic knowledge, executive function and famous face recognition Disinhibition
Mell et al., 2003	PPA (Non-Fluent)	MRI: bifrontal atrophy and mild temporal atrophy	I	Yes (art teacher)	Painting	Preserved visuospatial skills Non-fluent and effortful language Impaired executive tests
Serrano et al., 2005 (Pt 2)	PPA (Non-Fluent)	CT scan: diffuse cortical atrophy with left predominance	P	Yes (painter)	Painting	Preserved visuospatial skills Language deficits
Finney and Heilman, 2007	PPA (Non-Fluent)	MRI: focal atrophy of the left anterior temporal lobe and left insula	D	Yes (painter)	Painting	MMSE 25/30 Boston naming test 47/60 Categorical letter fluency 8 Preserved visuospatial skills
Seeley et al., 2008	PPA (d)	MRI: predominantly left inferolateral frontal atrophy SPECT: Predominantly left frontal hypoperfusion	I	Yes	Visual Art	MMSE = 20/30 Deficits limited to language and executive functions (span; fluency; TMT); Perseverations
Espinel, 1996	Mixed Alzheimer's disease	No imaging data	I	Yes (professional artist)	Painting	No neuropsychological data
Cummings and Zarit, 1987	Alzheimer's disease	No imaging data	D	Yes (professional artist)	Painting	MMSE: varies from 21 to 10 over 2.5 years Boston naming test: varies from 28 to 19 over 2.5 years FAS: varies from 7 to 0 over 2.5 years
Crutch et al., 2001 (and van Buren et al., 2013, Pt 1)	Alzheimer's disease	MRI: generalized brain atrophy	D	Yes (professional artist)	Painting Drawing	MMSE 22/30 WAIS 94 Calculation 0/24 Impaired visuospatial abilities Impaired verbal memory
Maurer and Prvulovic, 2004	Alzheimer's disease	No imaging data	D	Yes (professional artist)	Painting Drawing	Severe visuoconstructive deficits Prosopagnosia Gestural apraxia

(Continued)

Table 1 | Continued

Author and year	Diagnosis	Neuroimaging data	Change in abilities	Previous interest in Art?	Art domain	Neuropsychological data
Fornazzari, 2005	Alzheimer's disease	MRI: large arachnoid cyst SPECT: Bilateral temporo-parietal hypoperfusion	P	Yes (painter)	Painting	MMSE 26/30 Preserved visuospatial abilities Deficits in episodic memory, language, gestural praxis and executive functions
Serrano et al., 2005 (Pt 1)	Alzheimer's disease	CT scan: diffuse cortical atrophy	D	Yes (painter)	Painting	MMSE = 22/30 Impaired visuospatial skills Impaired executive tests (similarities, TMT) and memory
Chakravarty, 2011	Alzheimer's disease	CT scan: Diffuse cortical atrophy	E	No	Painting	MMSE = 16/30 CDR = 3
van Buren et al., 2013 (Pt 2)	Alzheimer's disease	No imaging data	D	No	Painting	Short term memory loss and emotional dysregulation Memory impairment
Kleiner-Fisman et al., 2003	Corticobasal degeneration	MRI: right-predominant atrophy PET-FDG: marked hypoperfusion on right hemisphere and left frontal region	D	Yes (professional illustrator)	Graphic Arts	Severely impaired visuo-spatial skills, spatial neglect Deficits on attention, initiation, memory and executive functions Poor insight Personality changes, irritability Apathy
Sahlas, 2003	Lewy Body Dementia	No imaging data	D	Yes (professional artist)	Painting Writing	No neuropsychological data but reports of deterioration of visuospatial functions
Drago et al., 2006a	Lewy Body Dementia	No imaging data	D	Yes (visual artist)	Painting	MMSE = 6/30 Poor orientation and apraxic gaze
Annoni et al., 2005 (Pt 1)	Stroke	MRI: left occipital region (V1 and V2)	I	Yes (professional painter)	Painting	MMSE = 29/30 Normal neuropsychological exam Emotional dysfunction Increased impulsiveness
Annoni et al., 2005 (Pt 2)	Stroke	MRI: left paramedian thalamus infarct	I	Yes (professional painter)	Painting	MMSE = 28/30 Normal neuropsychological exam Mild emotional dyscontrol Moderate tendency to perseveration in phonological and figural fluency No compulsive behaviors
Chatterjee et al., 2011 (Pt 1)	Stroke	No imaging data (left hemisphere stroke)	Change	Yes (professional painter)	Painting	No neuropsychological data
Chatterjee et al., 2011 (Pt 2)	Stroke	No imaging data (left hemisphere stroke)	Change	Yes (professional painter)	Painting	No neuropsychological data
Chatterjee et al., 2011 (Pt 3)	Stroke	No imaging data (right hemisphere stroke)	Change	Yes (professional painter)	Painting	No neuropsychological data but reports left spatial neglect

(Continued)

Table 1 | Continued

Author and year	Diagnosis	Neuroimaging data	Change in abilities	Previous interest in Art?	Art domain	Neuropsychological data
Takahata et al., 2014	Stroke	CT and MRI: infarction in the left prefrontal region	I	Yes	Painting	MMSE = 26/30 Preserved visuospatial abilities Deficits in episodic memory and executive functions Behavioral perseverations No impulsiveness and no compulsiveness.
Thomas-Anterion, 2009 (Pt 3)	Stroke	MRI: left posterior insula and parietal operculum infarct	E	No	Painting	Normal neuropsychological exam Compulsive art production with specific colors
Lythgoe et al., 2005	Subarachnoid hemorrhage	CT: no focal injury	E	No	Painting Poetry Sculpture	Almost normal, except difficulties in switching and inhibition control Patient obsessed with art
Galarza et al., 2014	Intracerebral hemorrhage associated to a cerebral arteriovenous malformation	MRI: extensive damage of left temporal lobe due to lobectomy.	Change	Yes	Music	Low performance in confrontation naming tests. Impairment on episodic memory tests for verbal modality, but not for visual modality. Preserved emotion recognition, except for fear.

This table synthesizes the published medical reports of changes in artistic skills in neurological patients. Abbreviations: CT, Computerized tomography; D, Degradation of artistic abilities; E, Emergence of artistic abilities; FTD, Frontotemporal dementia; I, Increase of artistic abilities; MMSE, Mini-Mental State Examination; P, Preservation of preceding artistic abilities; PET-FDG, Fluorodeoxyglucose positron emission tomography; PPA, Primary Progressive Aphasia; Pt, Patient; SPECT, Brain perfusion scintigraphy; TMT, Trail Making Test; WCST, Wisconsin Card Sorting Test. (a) Frontal FTD associated to ALS in a patient with previous bipolar disorder; (b) Frontal FTD due to Neuronal Intermediate Filament Inclusion Disease; (c) Temporal FTD associated to ALS; (d) Primary Progressive Aphasia due to corticobasal degeneration.

10 o'clock precisely. She also presented with repetitive and ritualistic behaviors such as compulsive writing, obsessions regarding time schedules and compulsive handbag checking. In this context, the patient started to produce drawings in a compulsive manner. Mrs. YCFZ also had memory complaints, but behavioral disorders remained the most impaired domain throughout the course of the illness. Basic activities of daily living were globally preserved, although she needed assistance for some instrumental activities such as financial operations.

The standard neurological examination was normal, without eye movement disorders or extrapyramidal signs. Formal neuropsychological evaluation (November 2010—**Table 3**) showed an impairment in global cognitive efficiency both on the Mini-Mental State Exam (MMSE: 16/30; Folstein et al., 1975) and on the Mattis Dementia Rating Scale (103/144; Porto et al., 2003). Executive tasks such as DRS initiation/perseveration subscale, FAS letter fluency and digit span were altered. There was a marked episodic memory deficit, which was characterized by low performance on both learning and delayed recall tasks from the Rey Auditory Verbal Learning Test (Malloy-Diniz et al., 2007) and in the DRS memory subscale. There was a moderate impairment in the naming task (9/15; Bertolucci et al., 2001). The visual abilities assessed using the Visual Object and Space Perception Battery (Warrington and James, 1991; Quental et al., 2013) were preserved (number location and cube analysis). The patient had no deficit on gesture execution, and no signs of Balint or Gertsmann syndromes. Brain computed tomography scanning in 2009 showed a remarkable atrophy in temporopolar regions bilaterally and a mild frontal polar atrophy (**Figure 1**). Brain MRI performed 2 years later showed no signs of cerebrovascular disease and confirmed the same regional atrophy pattern with additional diffuse brain shrinkage. On clinical follow-up after 36 months, the global cognitive efficiency assessed using MMSE remained stable (see **Table 4**), although language and functional abilities deteriorated, as assessed using the Functional Activities Questionnaire (Pfeffer et al., 1982). The diagnosis of probable bvFTD was retained on a clinical basis.

The patient was never notably interested in art. However, during the course of her disease, she began to draw compulsively on a daily basis (**Figure 2**). We sought to systematically analyze her drawing production using independent tools for this assessment. For this purpose, we used the consensual assessment technique (CAT; Amabile, 1982) to measure the global creativity of each drawing combined with a questionnaire adapted from Drago and colleagues (Drago et al., 2006a). The criteria assessed in this questionnaire included "Aesthetics": How beautiful is the painting? "Closure": How complete is the painting? "Abstraction": How abstractive is the painting? "Obsessions/Repetition": How obsessive/repetitive is the painting? "Evocative Impact": How strongly does the painting induce feelings or thoughts? "Novelty": How

Table 2 | Synthesis of cognitive, behavioral and artistic changes in previous published cases of patients listed in Table 1 and in our patient.

Pathology	Bv-FTLD	Temp-FTLD	nfPPA-FTLD	Alzheimer's disease	Other
Number of patients	11	19	4	8	12
Artistic emergence	5	11	0	1	2
Artistic increase (or preservation)	4 (1)	2 (6)	2 (1)	1 (1)	4 (3)
Artistic degradation	1	0	1	5	3
Artistic domain = visual	10	8	4	8	11
Intact visuospatial abilities	7 out of 7 reported	9 out of 10 reported	3	The degradation of artistic skills was associated with impaired visuospatial abilities in 6 cases out of 8 reported	
Positive behavioral symptoms reported					
Perseverations	3	2	1	–	1
Disinhibition	5	7	–	–	2
Compulsions obsessions	9	5	–	–	2
Negative dysexecutive symptoms reported					
1 or several deficits	10 out of 10 reported	7 out of 9 reported	3	3	3
Abstraction difficulties	5 out of 8 reported	–	–	1	–

This table summarizes the patterns of artistic changes (emergence, increase/preservation, or degradation of artistic abilities) and behavioral and neuropsychological findings in previously reported neurological patients. Neuropsychological deficits and behavioral disorders may be underreported due to the absence of specific mention in the original papers. "out of x reported" means the number of patients for which this given cognitive or behavioral aspect was assessed and reported in the article. We did not include Parkinson's disease because changes in creativity in these patients may be linked with dopamine rather than neurodegeneration. Bv-FTD, Behavioral variant of fronto-temporal lobar degeneration; temp-FTD, temporal variant of fronto-temporal lobar degeneration or semantic dementia; PPA-FTD, non-fluent primary progressive aphasia form of fronto-temporal lobar degeneration; Other, Corticobasal degeneration, Lewy body dementia, stroke, subarachnoid hemorrhage and cerebral arteriovenous malformation.

Table 3 | Neuropsychological assessment of the patient YCFZ (November 2010).

Test	Patient score	Standard deviation
MATTIS TOTAL SCORE (/144)	**103**	**−9.47**
MATTIS–Attention (/37)	33	−1.83
MATTIS–Initiation (/37)	19	−4.26
MATTIS–Construction (/6)	6	
MATTIS–Concepts (/39)	37	
MATTIS–Memory (/25)	8	−2.59
Verbal SPAN (DIRECT–INDIRECT)	**4–3**	
Rey auditory verbal learning test		
Immediate recall list A	18	−6.1
Delayed recall list A	0	−2.6
Recognition test list A	3	−4.3
NAMING (BOSTON–CERAD) (/15)	**9**	
FAS–Total	19	−9.9
Letter F	7	
Letter A	6	
Letter S	6	
VISUAL OBJECT AND SPACE PERCEPTION		
Number location (/20)	20	Cut-off: 9*
Cube analysis (/20)	20	Cut-off: 9§

**This cut-off distinguished controls from patients with early Alzheimer's disease with 63% sensitivity and 74% specificity (Quental et al., 2013).*

§This cut-off distinguished controls from patients with early Alzheimer's disease with 75% sensitivity and 68% specificity (Quental et al., 2013).

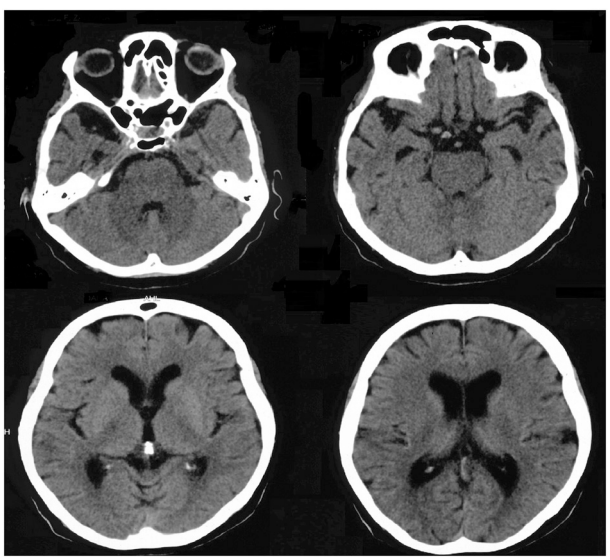

FIGURE 1 | Brain computed tomography scan performed in 2009 showing marked atrophy in bilateral temporopolar and frontal regions.

original or new is the painting? "Representation": How well is the subject of the painting rendered? "Technique": How much skill does the painting demonstrate?

We selected 20 drawings from May 2010 to September 2013 and asked 12 independent professional visual artists from Brazil (5 men, 7 women, aged from 31 to 70 years old, 5 of which

Table 4 | Longitudinal cognitive assessment of Mrs YCFZ, from November 2010–September 2013.

	November 2010	January 2011	May 2011	February 2012	June 2012	September 2012	November 2012	February 2013	September 2013
Time orientation (/5)	2	1	1	1	0	1	1	0	0
Spatial orientation (/5)	4	4	3	4	3	2	3	3	3
Registration (/3)	2	3	3	3	3	3	3	3	3
Mental calculation (/5)	0	1	1	0	1	1	0	0	2
Recall (/3)	0	0	0	0	0	0	1	0	0
Language (/8)	7	8	8	8	8	8	8	8	8
Copy (/1)	1	1	1	0	1	0	0	1	1
MMSE (/30)	**16**	**18**	**17**	**16**	**16**	**15**	**16**	**15**	**17**
Animal Fluency (Cut-off: 13)	9	7	5	5	6	NA	6	8	7
Functional Activities Questionnaire (0–30)	23	NA	NA	29	26	29	30	28	30

The table presents the MMSE total scores (in bold) and subscores for time and spatial orientation, registration of three words, mental calculation, recall of three words, language and copy of pentagons. Data for Animal Fluency and for the Functional Activities Questionnaire–FAQ (Pfeffer et al., 1982) for Activities of Daily Living are also presented. A cut-off point higher than 9 in the FAQ indicates impaired function and cognitive impairment. (NA, Not available).

FIGURE 2 | Drawings with higher and lower CAT scores. Left panel: drawings with the highest global scores (8.5 for the upper drawing, range 4–10; 7.4 for the lower drawing, range 3–10). **Right panel:** drawings with the lowest global scores (5.8 for the upper drawing, range 4–10; 6.0 for the lower drawing, range 2–10).

were professors at Fine Art universities, most of which had formal artistic training in Fine Arts) to judge the drawings according to global creativity and the criteria explored in the questionnaire. The experts were also encouraged to make free comments. This expert group was blind to the clinical condition of the patient, and no information on her artistic status or training was given.

The results of this evaluation are presented in **Table 5**. The mean global creativity score across experts and drawings was 6.6, but varied markedly depending on the expert, ranging from 3.2 to 9.6. Scores for each criterion also showed a considerable heterogeneity between the experts ranging from 0 to 10 for each drawing. This heterogeneity suggests that the 12 scorers, all experts in the domain of visual arts, had a different conception of what creativity and its related features should be.

CAT does not give an absolute assessment of creativity but provides relative scores enabling the comparison between different productions or different groups of participants. Therefore, we attempted to evaluate the evolving profile of the patient's drawings across time periods. First, we pooled drawings performed each year from 2010 to 2013 and looked at scores across the years (**Figure 3**). We observed an increase in scores from the first drawings (2010) to the last drawings (2013) in all of the evaluated aspects. Then, we statistically compared two periods: an early (drawings from 2010 and 2011; $n = 8$) and a late period (those from 2012 and 2013; $n = 12$) using a non-parametric Wilcoxon signed rank test. An increase in creativity scores was statistically significant for abstraction ($Z = -2.756$, $p = 0.006$), obsession ($Z = -2.045$, $p = 0.041$) and novelty ($Z = -2.312$, $p = 0.021$) subscores (**Figure 3**).

In their free comments, expert artists mentioned that most of the drawings were beautiful and creative, drawn with care, and found the compositions interesting or original. They insisted on the "naïve" character of the drawings, frequently describing them as simple and infantile ("these drawings are similar to those from my daughter of 6 years of age," translated general comment from expert 1). The experts agreed on the representational rather than abstract nature of the productions. Repetitions, obsessions, or stereotypies were diversely interpreted. Many experts highlighted the repetitive and obsessive character of the drawings, but they often found them useful for the composition, the expression, or the rhythm of the picture, and gave low obsession scores for this reason. There was a large variability in the scores for repetitions and obsessions (minimal 0, maximal 9.1, with a mean of 5.2). The drawings were often described as expressive and containing negative emotions ("sinister paranoid atmosphere," translated from expert 8 about drawing 19), but harmony was also evoked for some of them. Other comments highlighted bizarre or interesting compositions or strange/poor color choices.

Overall, the quantitative and qualitative creativity assessments showed great heterogeneity, especially in the general creativity of the drawings, the role of repetitions in the composition, or the emotional content. The disparity of judgment between

Table 5 | CAT assessment of the drawings from patient YCFZ (2010–2013).

	Global Score	Aesthetics	Closure	Abstraction	Obsessions/ repetitions	Evocative impact	Novelty	Representation	Technique
Artist 1	4.8	4.4	5.7	4.1	4.1	3.8	3.6	4.7	3.3
Artist 2	3.2	0.3	9.2	1.5	8.5	0.3	0.9	3.0	0.0
Artist 3	3.2	0.3	9.2	1.5	8.5	0.3	0.9	3.0	0.0
Artist 4	9.4	9.1	9.4	9.1	9.1	9.8	9.3	9.8	9.6
Artist 5	6.6	4.6	4.4	1.5	3.4	4.0	2.1	3.9	3.6
Artist 6	9.6	9.5	10.0	0.0	0.0	8.7	10.0	9.8	10.0
Artist 7	9.3	8.9	9.2	1.3	5.3	8.2	8.4	8.7	8.8
Artist 8	3.2	3.0	3.1	3.3	4.6	3.6	3.2	3.0	2.9
Artist 9	7.0	5.6	7.7	3.9	4.5	6.2	6.5	7.5	6.5
Artist 10	7.9	7.2	8.5	7.5	3.7	7.6	7.8	7.3	6.5
Artist 11	6.8	5.7	8.4	1.7	5.4	6.1	3.8	7.4	5.6
Artist 12	8.5	8.2	9.3	5.1	4.9	6.8	7.8	9.5	8.7
Mean	**6.6**	**5.6**	**7.8**	**3.3**	**5.2**	**5.4**	**5.3**	**6.4**	**5.4**
SD	**2.5**	**3.2**	**2.2**	**2.7**	**2.5**	**3.1**	**3.3**	**2.8**	**3.5**
Min	**3.2**	**0.3**	**3.1**	**0.0**	**0.0**	**0.3**	**0.9**	**3.0**	**0.0**
Max	**9.6**	**9.5**	**10.0**	**9.1**	**9.1**	**9.8**	**10.0**	**9.8**	**10.0**

The professional artists scored (from 0 to 10) each of the drawings for global creativity and according to the following criteria (adapted from Drago et al., 2006a): Aesthetics: How beautiful is the painting? Closure: How complete is the painting? Abstraction: How abstractive is the painting? Obsessions/Repetition: How obsessive/repetitive is the painting? Evocative Impact: How strongly does the painting induce feelings or thoughts? Novelty: How original or new is the painting? Representation: How well is the subject of the painting rendered? Technique: How much skill does the painting demonstrate? Mean scores attributed by each judge to the 20 assessed drawings are provided together with standard deviation, minimum and maximum values (in bold).

the professional artists with academic training for most indicates that personal subjectivity strongly influenced the scoring. Despite a large inter-judge variability, an improvement of the patient's artistic skills was considered during a 3-year evolution period, especially for the abstraction, novelty, and repetition criteria, while language and autonomy declined. This suggests that the artistic creative capacity of the patient did not parallel her cognitive deterioration.

This observation is consistent with the potential emergence of an artistic inclination during the evolution of bvFTD, as previously reported, and highlights the interference between cognitive and behavioral frontal symptoms and creative production.

DISCUSSION: WHAT DO ARTISTIC PATIENTS TELL US ABOUT CREATIVITY?

The difference between controlled patient studies and medical reports of creativity following frontal damage raises interesting questions regarding the mental components of creative thinking, their measurements, and their neural bases. Experimental approaches of creativity have demonstrated that various PFC regions are critical to creative capacity. Conversely, some frontal patients exhibit new or significant artistic productions despite their frontal dysfunctions, as was the case for the reported patient. Can this be explained? Does this mean that their creative capacities increased?

CLINICAL CONSIDERATIONS FOR PATIENTS WITH NEW OR SIGNIFICANT ARTISTIC PRODUCTION

Artistic facilitation is a rare phenomenon in neurological patients. The link between artistic production and neurological diseases appears to be anecdotal, especially when the high incidence of strokes and neurodegenerative diseases are considered. SD (FTD with temporal prominent atrophy) is the most frequent diagnosis associated with increased creative production (**Table 2**). In contrast with controlled studies that included unselected patients with neurodegenerative diseases, case reports point to particular patients who are especially concerned with making art. To our knowledge, no such exceptional patient with artistic facilitation has been explored using theory-based creativity tests. So it cannot be ruled out that controlled studies with unselected patients may miss some exceptional patients.

Because artistic facilitation has been observed in diseases as different as temporal and frontal variants of FTD, Alzheimer's disease, or stroke affecting distinct brain regions, clinical reports do not argue for a specific neuroanatomical or neuropsychological pattern associated with enhanced artistic production. For instance, it has been proposed that the emergence of artistic talent in FTD patients results from the release of the inhibition exerted by anterior regions over the posterior regions involved in visuospatial processing (Kapur, 1996; Mendez, 2004; Seeley et al., 2008). This theory may not explain the improved or preserved creative output in patients with predominant posterior injury (Annoni et al., 2005; Fornazzari, 2005) or in patients with no frontal dysfunction (Schrag and Trimble, 2001; Thomas-Anterion et al., 2010). Nevertheless, it is remarkable that most positive changes of artistic abilities concerned visual arts (41 cases out of 54 reviewed, including the current case report) when most patients had preserved visuospatial skills each time this was reported. In the related cases of creative production associated with either bvFTD or SD, degeneration mostly affected

the left temporal and/or frontal regions, which may explain the predominance of visual arts in the patients' production being more related to the visuospatial functions of the right hemisphere. However, Wu and colleagues (Wu et al., 2013) recently reported two SD patients in whom the emergence of artistic activities in the verbal domain was associated with a predominantly left atrophy. Additionally, this left-right hypothesis is not in agreement with functional imaging data, as the meta-analysis from Gonen-Yaacovi and colleagues demonstrated a left dominance of activation in both verbal and visual tasks. Unfortunately, most of the published clinical reports do not provide extensive or detailed neuropsychological and anatomical data, which would enable a better characterization of the relationship between frontal or visuospatial alterations and creative output.

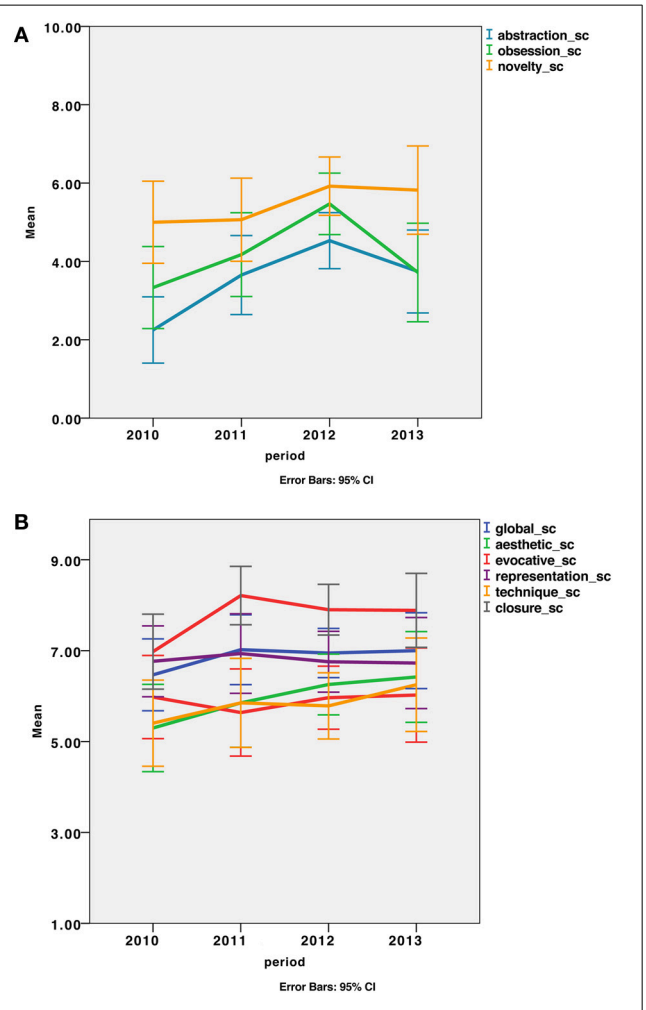

FIGURE 3 | Scores of the drawings across a 36-month period. (A) Subscores with a significant improvement between the first (2010–2011) and the second period (2012–2013) of the drawings. Significant increases were observed for the abstraction, obsession and novelty subscores. **(B)** The global score and several subscores did not show a significant improvement between the first and the second period, though all scores increased.

TIES BETWEEN FRONTAL SYMPTOMS AND ARTISTIC PRODUCTIONS

Some behavioral disorders associated with frontal damage may account for or parallel artistic expression, as suggested previously (Rankin et al., 2007; de Souza et al., 2010; Palmiero et al., 2012; Schott, 2012) and highlighted in our reported case. From a neurological point of view and based on the neuropsychological profile of our patient, we fist concluded that some frontal symptoms are possibly interfering with the drawings, while preserved visuospatial abilities enable their execution. The urge to draw on a daily basis and the huge amount of productions are possibly related to personality changes and compulsive behaviors provoked by frontal damage. Repetitive topics (plants, animals, people) and patterns (volcano, leaves) may be the manifestation of perseverations and stereotypies due to the frontal syndrome. Strange composition and infantile features may be explained by poor planning abilities (**Figure 4**).

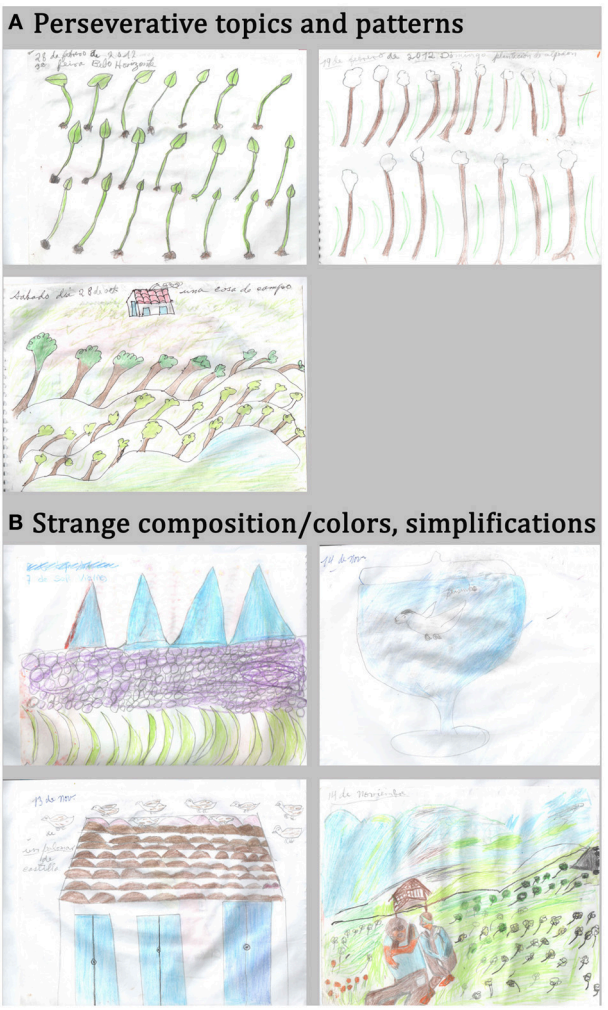

FIGURE 4 | Possible frontal manifestations expressed in the patient's drawings. (A) Perseverative topics and patterns. **(B)** Strange composition, color choices and simplifications.

Many patients with so called "artistic improvement" presented compulsive and/or obsessive behaviors (Finkelstein et al., 1991; Miller et al., 1998; Miller and Hou, 2004; Lythgoe et al., 2005; Serrano et al., 2005; Thomas-Anterion et al., 2010). As pointed by Schott (2012), in such patients, "a strong preference for a single art medium, a restricted focus on artistic themes, repetition, compulsion and seeking for perfection (. . .) enabled remarkable artistry to be achieved." The patient we report on also produced drawings in a compulsive manner; this may partly account for the acquisition of an artistic technique. The fact that her last drawings received higher scores than the first drawings (produced 3 years prior) supports this assumption. Compulsive and/or obsessive behaviors are a major symptom of bvFTD (Rascovsky et al., 2011). These behaviors are surprisingly in contrast with the apathy also frequently observed in bvFTD, as well as with the cognitive inertia associated with a poor fluency, as was the case in our patient. Compulsive behaviors are usually associated with severe disorders of social conduct. For example, the patient reported by Miller et al. (1998) developed new photographic skills during the course of FTD. Pictures were taken compulsively to obtain a "perfect image." However, at the same time, this compulsive demeanor also produced socially inappropriate behaviors, leading to severe social constraints, and ultimately to institutionalization. The patient we report also had ritualized behaviors that also led to social misconduct. In other words, the repetitive and ritualized behaviors related to frontal dysfunction may be expressed in the artistic domain, leading to new interests in making art or intense artistic activity with repetitive topics or productions. The reasons why some patients focus their compulsive behaviors on making art and others do not remain poorly understood.

Perseverations or patterning, which are also linked to frontal damage, were observed in our patient's drawings (trees and leaves, for instance). Surprisingly, our expert group remarked repetitions and made free comments about them but did not give especially high scores on the repetition criteria because they did not feel it was inappropriate or unaesthetic. A previous case-control study of creative production across bvFTD patients and normal controls (de Souza et al., 2010) showed that behavioral disorders, such as perseverations, may also partly explain the "originality" of some productions when frontal patients perform divergent thinking tests, but overall their originality score was impaired. Similarly, disinhibition, another cardinal symptom of frontal dysfunction, can interfere with creative activities, as also noted by de Souza et al. (2010); however this was not observed in the current case. Social disinhibition can lead to unexpected choices of topics, for instance with sexual content. The release of the inhibition exerted by frontal regions over the posterior regions may explain some unconventional or socially unusual aspects of creative productions as well as behaviors in frontal patients (Miller et al., 1996; Mell et al., 2003; Mendez, 2004; Miller and Hou, 2004; Drago et al., 2006b; Seeley et al., 2008).

In the cognitive sphere, some frontal lesions may help in overcoming knowledge constraints (Reverberi et al., 2005; Abraham, 2014). Patients with lateral prefrontal damage may experience a less sculpted (less constrained) response space in a given context than healthy subjects, enabling them to more easily consider any option, including those outside of contextual constraints (Reverberi et al., 2005). Overall, disinhibition or the loss of social conventions and associative knowledge may allow the emergence of creative productions (Miller et al., 1996, 2000; Miller and Hou, 2004; Liu et al., 2009). According to Rankin et al. (2007), productions from bvFTD patients may have an artistic value in the sense that they are freer from conventional representations and social conventions about art. It is more difficult to assume that this freeing from convention is an intentional and voluntary act.

Finally, our patient's drawings share other qualitative features that have been reported in previous FTD patients, especially with those described in Rankin and colleagues' study (Rankin et al., 2007) in which patient productions were assessed by scientists who had an interest in arts and not by professional artists. For instance, landscapes, people, animals and plants appear to be the preferred topics in frontal patient's productions. These preferred topics may be considered to be conventional and concrete but are often represented in an unusual way. The simplification of representations, judged as naïve or infantile, and unconventional or disordered composition with eccentricity of the subject, could be linked to a poor planning ability and lack of abstraction but could also contribute to the bizarreness and unusualness of the drawings.

Together, patient observations indicate that some clinical and behavioral symptoms of frontal dysfunction may facilitate the appearance of creative features in artistic products. This explanation cannot stand in the domain of creativity in which other frontal functions such as cognitive control, planning, mental manipulation, and abstraction are critical. Additionally, these observations raise the question of whether the artistic productions we observe reflect the same aspect of creative capacity and result from the same voluntary creative processes that are assessed in experimental creativity studies.

ARTISTIC AND NEUROSCIENTIFIC PERSPECTIVES

Patient studies and clinical observations may highlight the probable difference between creativity evaluated from an artistic point of view and creativity evaluated from a neuroscientific perspective. In the field of Art, aspects such as emotional or evocative impact, provocation and message, aesthetic value, or technical mastery may be more important than in other domains such as sciences and technology. These aspects are not captured by the consensual definition of creativity that focuses on originality and appropriateness. Within the frame of this definition, a difference may also be noted: originality may often be considered to be a predominant condition for creativity in the artistic field in which appropriateness is difficult to apprehend; however, in other domains such as science, appropriateness is a requirement. For example, patients studied in de Souza et al. (2010) were often inappropriate in their responses, while no control subjects were. The sexual content of their drawings may be regarded as inappropriate in an experimental testing context but is usually well accepted in artistic works. This suggests that each domain of creative expression differently prioritizes originality and appropriateness and makes different demands on the mental operations to achieve them.

It is also important to mention that experimental and neuroimaging approaches do not assess motivational, conative, or

emotional factors affecting creative drive. However, these factors appear to be important in real life creativity, such as in the spontaneous productions of patients with an artistic preoccupation. As highlighted by Schott (2012), these patients are often described "as obsessive about their art, with an urge to create." It is then possible that emotional and motivational factors play an important role in real life creativity, including artistic creativity, but are poorly accounted for in experimental approaches of creativity. The latter are indeed based on cognitive theories of creative capacity with limited assessment of the emotional and conative aspects.

In our case, the score of evocative impact, which is intended to depend on the emotional expressiveness of the drawings, varied between the experts (0.3–9.8, with a mean value of 5.4). One method for analyzing the importance of emotional process in the artistic production of the patient would be to study the correlations between the scores on the CAT and objective measures of social-emotional cognition such as emotion recognition, empathy, and theory of mind. Unfortunately, these domains were not evaluated in our patient.

Finally, the difference between real life and experimental settings for measuring creativity is also in question. The evaluation of spontaneous patient productions was generally based on subjective assessments from authors, experts, or groups of judges. Our clinical case illustrates that subjective assessment, although framed by determined criteria and performed by experts in the field of visual arts, has a great inter-individual variability. Experimental theory-based approaches use more objective criteria to measure creative capacity, for instance fluency, flexibility, originality, or problem solving success. Several of these cognitive approaches have been used to study the neural basis of creativity in functional neuroimaging and in neurological patients. If theory-based approaches use more "objective" criteria, they are constrained by the hypothesis that they rely on. In other words, creativity tasks only assess the processes involved in creative capacity according to the cognitive model used. Each theory-based approach focuses on one or more aspects of the creative process, but none of them evaluates the creativity in all of its dimensions. In particular, theory-based creativity tasks do not necessarily capture artistic quality, even though they have been shown to be ecologically valid and statistically linked with artistic creativity (Kim, 2006; Plucker and Makel, 2010). On the contrary, theory-free creativity assessments, such as CAT, are not based on any particular theory of creativity, which means that their validity is not dependent upon the validity of any particular theory. Unfortunately, our patient was no longer able to perform experimental creativity tests at the time of the consultation; thus, we are not able to compare both approaches to creativity assessment in a case of artistic preoccupation.

Overall, the creativity attributed to patients preoccupied with arts during a frontal disease and creativity explored in experimental studies differ in several conceptual and experimental ways, and are probably affected differently by frontal symptoms.

OVERALL, CAN HYPOFRONTALITY FACILITATE CREATIVITY?

A common notion suggests that losing control, especially relaxing social and emotional inhibitions or conventions, may favor personal expression and creativity. The use of drugs such as alcohol may aim to approach this state. Several artistic streams are based on the spontaneous, non-controlled generation of ideas or objects, for instance using automatic writing or random painting. In the neuroscientific literature, some studies suggest that unconscious and uncontrolled processes facilitate divergent thinking and insight problem solving (Yaniv and Meyer, 1987; Dijksterhuis and Meurs, 2006; Dorfman et al., 2008; Zhong et al., 2008; Ritter and Dijksterhuis, 2014). Because control in behavioral, affective, social and cognitive spheres is largely associated with the functions of the PFC, the notion that hypofrontality could favor creativity may be valid. A recent theory (Chrysikou et al., 2013) also postulates that hypofrontality may enhance some aspects of creativity: the availability of bottom-up information that is usually filtered by the PFC may favor a breaking away from rule-based thinking. This is reinforced by the fact that some frontal patients appear to have abilities in some aspects of artistic expression.

The current review identified several clinical aspects of hypofrontality in the social, conative and cognitive domains that could explain some creative features of the patients' products. First, a social aspect related to the common view of hypofrontality is disinhibition. Social disinhibition can lead frontal patients to break with social conventions and propose unusual productions in creative (but also in uncreative) activities. Second, compulsive, repetitive or obsessive behaviors may lead to high productivity and improvements in technical skills. This obsessive-compulsive trait acts as a strong motivation toward a given activity. A third and more paradoxical aspect consists of a lower influence of habitual contextual associations in frontal patients. Patients with lateral PFC damage may be less constrained by learned rules, which may facilitate some problem-solving tasks (Reverberi et al., 2005). This aspect is paradoxical because it is in apparent opposition to the acknowledged role of the inferolateral PFC in overcoming prepotent responses [as observed in functional imaging and patient studies using Stroop tasks, no-go tasks or Hayling tasks (Aron et al., 2003; Brass et al., 2005; Picton et al., 2007; Volle et al., 2012), as well as in contextual control (Azuar et al., 2014)]. Overcoming prepotent responses and contextual control are both thought to play a role in creativity. Thus, whether highly creative people among the general population have more relaxed contextual constraints (as frontal patients may have) or increased abilities to intentionally overcome these constraints is an interesting topic for future research.

If hypofrontality generally evokes signs of disinhibition and poor control (usually associated with lateral and ventral portions of the PFC), we should also consider other roles of PFC in cognition that have been more recently highlighted. For instance, the medial PFC is part of the default network (Buckner et al., 2008), a set of functionally connected brain regions in which activity decreases when tasks require more focal attention, effort, or control. This network has been associated with spontaneous cognition and mind wandering (Gilbert et al., 2007; Mason et al., 2007; Christoff et al., 2009; Andrews-Hanna et al., 2010). This network can be distinguished from the set of regions functionally connected to lateral PFC (Gilbert et al., 2010). Some recent studies highlighted the role of the default network and of spontaneous cognition in creativity

(Takeuchi et al., 2012; Wise and Braga, 2014). Medial PFC is also involved in semantic processing (Buckner et al., 2008; Binder et al., 2009) and in semantic aspects of creativity (Green et al., 2012; Abraham, 2014). These data suggest that the lateral PFC is engaged in rule-based thinking, while the medial PFC appears to be involved in a more spontaneous mode of thinking such as associative thinking. The rostral PFC may act as a switch (Burgess et al., 2007) between these two modes. Both thinking modes are thought to be required for creativity, as suggested in several models (Vartanian et al., 2007; Gabora, 2010; Ward and Kolomyts, 2010; Ellamil et al., 2012). For instance, the uncontrolled association of ideas triggered by perceptual or emotional stimuli may favor unusual responses but may also lead to inappropriate responses if the control mode does not filter. How each mode is affected by frontal lesions and how it impacts creative capacity is poorly known. The consequences of damage to the rostromedial PFC on creativity may lead to poorer originality (de Souza et al., 2010; Shamay-Tsoory et al., 2011), but the mechanisms of this change and its relationship with the default network functions are unexplored.

Overall, the classical view in which PFC supports top-down controlled processing while subcortical and posterior brain regions are engaged in bottom-up uncontrolled processing may be more balanced regarding creativity. If the lateral PFC is largely associated with top-down control, some other PFC regions may be involved in the uncontrolled or bottom-up processing that is spontaneous cognition, including semantic associations and mind wandering. The interaction between controlled and spontaneous cognition *via* connectivity between the lateral and medial PFC networks (Spreng et al., 2010) may enable both original and appropriate ideas to emerge.

CONCLUSION

The functional and anatomical organization of the PFC supports different aspects of behavioral adaptation in humans, suggesting its role in the adaptive aspects of creativity as they are emphasized in its definition (i.e., creating something original and appropriate). Functional neuroimaging and experimental patient studies also suggest that the PFC, in particular the anterior PFC, may also play a critical role in originality aspects of creativity. Damage to the PFC may alter the intentional appropriateness and originality of patient productions by altering planning, fluency, mental flexibility, rule-based thinking, or abstraction. However, clinical observations of frontal damage patients suggest that some symptoms associated with frontal damage provoke cognitive, conative, and behavioral changes, including social disinhibition, compulsive behaviors, emotional distortions, and the relaxing of cognitive constraints, which can motivate and favor artistic productions. However, artistic production is not synonymous with creativity, because creativity refers to aspects such as emotional expression, evocative impact, aesthetic, and technical abilities, which are present in art but not necessarily in other domains of creativity. Art is thus difficult to capture using theory-based creativity tasks, and to our knowledge, patients with facilitation in the artistic domain have not been tested experimentally with such tasks. Therefore, whether these rare frontal patients increase their real creative capacity does not have a yes or no answer. Using theory-based creativity tasks, functional imaging and patient data suggest that distinct PFC subregions differently affect the different aspects of creativity. PFC cannot be considered as a unitary structure, and exploring its organization and interactions subserving different creativity processes, including controlled and spontaneous cognition, as well as social and affective aspects, may provide a more precise answer.

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"Not in their right mind": the relation of psychopathology to the quantity and quality of creative thought

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The empirical link between psychopathology and creativity is often correlational and fraught with suspiciously causal interpretations. In this paper, we review research in favor of the position that certain forms of psychopathology that profoundly affect the neural substrates for rule-based thought (e.g., schizophrenia, bipolar disorder) can significantly influence the quantity of creative production. Because highly productive individuals, irrespective of psychopathology, often produce work of greater quality, it seems that such an increase in the quantity of one's output positively affects the likelihood of generating those statistically rare acts and achievements identified and celebrated as creative. We consider evidence that offers support for such a claim. In addition, we explore findings from neuroscience that can address how a neural mechanism, the flexibility of which relies on tradeoffs between rule-based (e.g., prefrontal cortex) and stimulus-based (e.g., sensorimotor cortex) brain regions, is influenced by psychopathology in ways that can alter dramatically the quantity and quality of creative output.

Keywords: madness, creativity, psychopathology, prefrontal cortex (PFC), hypofrontality, bipolar disorder, schizophrenia, genius

INTRODUCTION

There is an undeniable empirical link between psychopathology and creativity. By its very nature, however, much of this work on the "mad genius" is correlational or otherwise methodologically compromised and still fraught with suspiciously causal interpretations (Schlesinger, 2009). In this paper, we first discuss how the persistence of an ancient historical link between creativity and psychopathology has contributed to the acceptance of recent empirical evidence at face value, despite its serious methodological shortcomings. We then review research that points to a more nuanced interpretation of these positions, namely that certain forms of psychopathology that profoundly affect the neural substrates for rule-based thought can significantly influence the quantity of creative production. We propose that psychopathology that alters prefrontal cortical filtering increases creative production and, thus, the likelihood of high-quality creative work. We argue that the link between psychopathology and creativity is indirect, such that, at least under certain circumstances, the quantity of the creative output begets its quality.

THE HISTORICAL LINK BETWEEN CREATIVITY AND MADNESS

What is the historical and cultural link between psychopathology and creativity that it should be so pervasively held today? In Plato's (1987; trans.) dialog, *Ion*, one is told that "[a] poet... is a light thing, and winged and holy, and cannot compose before he gets inspiration and loses control of his senses and his reason has deserted him" and further that poets can only compose "not by virtue of a skill, but by divine power" (534b–c). From this rather singular source, Western culture inherits a certain ironic awe of creative individuals. Poets (in particular) are special, set apart, and close to the divine. Unfortunately, for Plato, they are also of little use, for as much as they are sporadically close to the gods, their practice misrepresents the nature of reality (e.g., in contrast to practiced philosophy and dialectic, which allows one to glimpse beyond the world of appearances); they also fail to educate the youth morally. Regarding the latter, a poet is an emotional creature and truly only superficially knowledgeable of warfare, medicine, carpentry, etc., even though such topics might arise in their compositions; thus, if they are not experts or skilled with even these matters, how could they be consulted or trusted for matters so important and lofty as how one ought to behave or the nature of right and wrong?

What is hard to believe about still regarding the creative individual as somehow "possessed" or "inspired" (which literally suggests a vessel being "breathed into," in+spire) is that it is based on an ancient argument that sought to privilege philosophers over poets (and rhapsodes) as authorities in the Greek world, especially in regards to a general theory of knowledge and the good (see also Plato's *The republic*). Without such an ontological or epistemological commitment, modern creativity researchers should not be so beholden to this position. Indeed, from a modern research standpoint, studying the creative process given Plato's account would be extremely problematic anyway because the process is essentially regarded as irrational (or non-rule-based) and—more to the point—its source problematically external to the very individual in the throes of creation. Interestingly, much of the Ancient Greek world did not hold such a "passive" view of poets; there was a comfortable overdetermination of causation in which a poem was both divine and consciously composed (see Murray, 1981). Muses did not absolve responsibility; they were

the personification of inspiration, which was the purposeful use and appeal by the poet to perfectly ordinary cognitive processes like memory and knowledge, as well as processes that assisted in meeting the needs of an audience (e.g., fluency in composition or performance). There was a respectful balance between what modern researchers can regard as non-conscious productive processes and those deliberate, more controlled processes. The historical and cultural link between psychopathology and creativity is fascinating, but it was never a necessary one for either layperson or scientist. It is worthwhile to consider how research on creativity (at least with respect to its relation to psychopathology) would be different had views on "possession" been more moderate.

THE QUANTITY OF CREATIVE PRODUCTION AND THE THIRD VARIABLE PROBLEM

Perhaps because of the persistent (though problematic) link between psychopathology and creativity described above, the more recent empirical one has been easier to establish and accept—this, despite small sample sizes, lack of generalizability, lack of statistical significance, lack of proper control groups, etc., (see Schlesinger, 2009). Andreasen (1987) famously interviewed writers at the University of Iowa Writers' Workshop and reported that 80% had at least one episode of an affective disorder, two and half times the level of control participants, and that four times as many writers had a bipolar disorder diagnosis than control participants. This link extended to first-degree relatives, who themselves had an increased level of psychopathology. Jamison (1989) also reported high levels of diagnosis of and treatment and medicalization for affective disorders in poets and playwrights. The vast majority of participants also admitted to feelings of enthusiasm, euphoria and well-being, high energy, and fluency of thought during creative episodes, suggesting a link between hypomania specifically and creativity.

Contrary to these standard accounts suggesting that psychopathology "leads" to creativity, some have even proposed that creative work may instead precipitate the occurrence of psychopathology (which is at least a logical possibility, see Ramey and Weisberg, 2004); Kaufman and Baer (2002) have concluded that a craft and profession like poetry-writing might simply attract those predisposed to psychopathology in the first place; Ludwig (1998) has found that the psychopathology-creativity link depended on the extent to which a profession or subject matter was more formal (e.g., science) or subjective (i.e., arts); but such voices are the minority. The ultimate issue here is one of explanatory motivation. Even with essentially correlational designs, many studies' conclusions are simply unidirectional with respect to explanation or insinuation. In fact, a third-variable problem also presents itself such that any relation between psychopathology (e.g., measured by diagnosis) and creativity (e.g., measured by the quality of a poem) could actually be accounted for by their relation to some other variable (e.g., the quantity of that which is produced, itself related to energy and motivation to produce in the first place). For example Ramey and Weisberg (2004) tested the hypothesis and posthumous diagnosis offered by McDermott (2001) that Emily Dickinson exhibited symptoms of hypomania during her lifetime and that poems written during these periods would be "more creative" than poems written during other times (presumably when she did not suffer from any mood disorder). Poems written during hypomanic years were, in fact, more likely to appear in anthologized works of poetry (a measure of creativity, or quality) than poems written during other years. This relation, however, was confounded when Dickinson's productivity was taken into account: she also wrote *more* during her hypomanic years. When they analyzed her so-called non-mood-disordered years, the likelihood of writing a quality poem also increased in years that she was more productive. Thus, it was productivity, irrespective of psychopathology, that explained the relative creativity of her poetry (see also Simonton, 2004; for a similar link between quantity and quality). In an investigation of the relation between depression and creativity, Verhaeghen et al. (2005) concluded that rumination, or the extent to which one focuses on oneself or the causes of one's mood, accounted for one's creativity, not depression, and that "self-reflective rumination prepares individuals to generate a larger number of ideas" (p. 230). Many of the creative arts may, thus, function as an accommodating outlet for such self-reflection. In fact, upon closer examination, it seems that in studies of both eminent and everyday creativity, the link between psychopathology and creativity is never one of extreme, incapacitating "madness" and creativity (see Richards and Kinney, 1990). Rather, the link is between creativity and certain symptoms (e.g., of hypomania) like focused motivation and drivenness to create or achieve some goal. In fact, 90% of the writers in Jamison (1989) indicated that such moods were either integral or at least very important to their work (see also Jamison et al., 1980). These are states in which the non-pathological may also find themselves and be creative. An increase in the quantity of one's output positively affects the likelihood of generating those statistically rare acts and achievements identified and celebrated as creative. Productivity, self-reflection, and elevated moods likely serve as reinforcers for such continued practice. What is critical, it seems, is a balance between unfettered productivity and a more controlled deliberation and evaluation of the volume of produced material. Modern research in the cognitive and brain sciences, with no overt ties to Plato, offers an account of creativity under just such a premise.

NEURAL MECHANISMS SUPPORTING CREATIVE THOUGHT AND THE INFLUENCE OF PSYCHOPATHOLOGY

Recent neuroscience research has highlighted the potential contribution of both spontaneous and controlled processes to creative thought (Zabelina and Robinson, 2010). Coming up with novel ideas or solutions necessitates the ability to generate unexpected associations, which fosters originality and uniqueness. Generating a creative product also requires the ability to evaluate the viability and efficacy of different available possibilities, as well as an uninterrupted focus on the creative task until its completion; this latter process is generally referred to as *cognitive control*. Cognitive control underlies most aspects of higher-order cognition, from attention, language, and memory to decision-making and problem solving. This set of top-down, regulatory mechanisms is supported by the prefrontal cortex (PFC) and promotes the salience of certain bottom-up, sensory information from either the environment or the internal state of the organism toward

context-appropriate responses. Likewise, access to bottom-up, sensory information that is deemed irrelevant for the task at hand is diminished or eliminated (Shimamura, 2000; Miller and Cohen, 2001). Although this process of regulatory filtering is undeniably beneficial for complex cognition, under certain circumstances exerting top-down influences might constrain or impede performance on tasks that benefit from spontaneous, bottom-up thought. This tradeoff is captured by the matched filter hypothesis (MFH) for cognitive control (Chrysikou et al., 2013b), a recent theoretical proposal that highlights potential competing interactions between prefrontal and posterior or subcortical brain systems that determine the appropriate level of cognitive control filtering over bottom-up information for optimal task performance. The MFH contends that PFC-mediated cognitive control is advantageous for explicit, rule-based tasks, involving the manipulation of information that does not exceed the representational capacity of working memory, whereas the exertion of cognitive control is counterproductive for more automatic tasks, involving information that surpasses working memory limitations. For these tasks, decreased PFC regulatory filtering and increased involvement of posterior or subcortical systems (e.g., sensorimotor cortex, basal ganglia) best supports performance (see also Thompson-Schill et al., 2009).

This proposal offers a potentially ideal explanatory framework for the neural processes involved in creative thinking generally, in addition to the likely consequences of psychopathology for creative production. It has been argued that creative thought involves a flexible modulation of cognitive control that allows the creative individual to achieve an optimal balance between spontaneous and controlled processes during the different phases of creative production (see Hélie and Sun, 2010; Zabelina and Robinson, 2010). Recent neuroscientific evidence suggests that certain data-driven creativity tasks may benefit from a state of hypofrontality, wherein limited PFC regulation and the attendant unconstrained contribution of posterior sensorimotor regions support the availability of unfiltered (low-level), raw perceptual input. For example, participants who were asked to generate an uncommon use in response to pictures of common objects while undergoing fMRI showed an increased involvement of posterior, visual object-processing regions (i.e., occipitotemporal cortex), bilaterally, but they did not show significant activity in left ventrolateral PFC regions; in contrast, participants asked to generate the common use for the same objects showed the reverse effect (Chrysikou and Thompson-Schill, 2011). What's more, inhibiting the left inferior PFC using transcranial direct current stimulation (tDCS) increased the speed in which participants generated uncommon (but not common) uses for everyday objects, as well as the number of responses generated, whereas inhibiting the right PFC or sham stimulation did not affect performance on either task (Chrysikou et al., 2013a). Critically, patients with primary progressive aphasia, a neurodegenerative disorder that primarily affects left PFC, experience increased visual accuracy in spontaneous drawing, which was not present prior to the onset of their disease (e.g., Seeley et al., 2008; Shamay-Tsoory et al., 2011). Thus, patients diagnosed with certain neuropsychological disorders that selectively diminish PFC function exhibit increased access to bottom-up sensory information that can enhance their performance on some data-driven, higher-order cognitive tasks. Overall, in line with the MFH, a hypofrontal cognitive state can be beneficial for certain bottom-up, creative generation tasks. On the other hand, other aspects of creativity likely necessitate the contribution of top-down, PFC-guided regulatory mechanisms. For instance, evaluating the appropriateness of different novel ideas requires frontal cortex mediation to assess which solution is optimal for the task at hand (e.g., Ellamil et al., 2012). As such, creativity involves rapid shifting between a hypofrontal, generative state and a PFC-guided evaluative state, a flexible and dynamic process that likely occurs iteratively numerous times until the optimal solution to a creative task is achieved (Hélie and Sun, 2010; Chrysikou et al., 2013b).

We argue that the negotiation of the tradeoffs between rule-based and data-driven neurocognitive systems in different creativity tasks can be altered by vulnerability to certain neuropsychiatric disorders characterized by PFC hypofunction such as bipolar disorder and schizophrenia. A substantial body of work has revealed that patients with schizophrenia exhibit abnormal PFC profiles marked by either lower or inefficient frontal cortex function in response to tasks that require cognitive or affective inhibition (e.g., Perlstein et al., 2003; Koike et al., 2013; Eich et al., 2014), but not perceptual filtering (e.g., Smith et al., 2011). Furthermore, a simultaneous analysis of global anatomical and functional connectivity has revealed both lower structural connectivity and diminished coherence (i.e., either abnormally increased or decreased connections) in functional connectivity among different brain regions in patients diagnosed with schizophrenia, relative to healthy control subjects, that was predictive of symptom severity (Skudlarski et al., 2010). Similarly, patients with bipolar disorder marked by psychotic features have been shown to exhibit significant disruptions in the frontoparietal control network (e.g., Baker et al., 2014). Such neurocognitive abnormalities in these forms of psychopathology may prolong periods of hypofrontality in the patients, thus altering dramatically the quantity of creative output by increasing the generative phase of creative production. As patients periodically shift to states of higher PFC regulation (e.g., as a result of pharmacological treatment), the likelihood of encountering and identifying particularly viable, high-quality creative ideas increases, due to the overall increased volume of their creative output. We note that this model is in line with evidence suggesting higher creativity in patients with mild forms or those at risk of these disorders (e.g., Richards and Kinney, 1990; Johnson et al., 2012) and not in those diagnosed with severe cases of psychopathology characterized by very limited or non-existent regulatory function. In brief, too little PFC regulation may significantly impair the quality of creative output, whereas too much PFC regulation may limit the quantity of creative production and, as a result, also hinder the likelihood of generating an idea that would be characterized as highly creative (see also Abraham, in press; Abraham et al., 2007).

CONCLUSION

Much of past research on the relationship between psychopathology and creativity is marred by serious methodological limitations, correlational designs, and problematically unidirectional

interpretations, the prevalence of which might be attributed to the curiously persistent historical link between creativity and "madness." Here we propose that, independent of psychopathology, highly productive individuals often produce work of greater quality. As such, an increase in the quantity of one's output positively affects the likelihood of generating those statistically rare acts and achievements identified and celebrated as creative. We argue that creativity may depend on a dynamic filtering mechanism, the flexibility of which relies on tradeoffs between rule-based (e.g., PFC) and stimulus-based (e.g., sensorimotor or subcortical) brain regions, and which, when influenced by psychopathology, can alter dramatically the quantity—and so quality—of creative output.

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Creative cognition and systems biology on the edge of chaos

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Complexity theorists have suggested that production "on the edge of chaos" is important to self-organization and evolutionary change in thermodynamic systems, biology, and economics. We apply this heuristic to cognitive systems and neural network activation states, which can vary from an ordered (predictable) regime, to a chaotic (unpredictable) regime. Evolutionary cytoarchitectonic theory specifies complementary anatomical systems governing stability and flexibility. Psychopathology is associated with shifts in the regulation of stability and flexibility, and may yield both increased redundancy and increased entropy *within* the same individual. We suggest this fits existing literature showing: (a) examples of exceptional creativity in individuals with mental illness, without an overall increase in creative achievement associated with "madness"; (b) increases in creative achievement among relatives of people with mental illness, or people with milder syndromes, for whom increased flexibility or stability is less disabling; and (c) effects of pharmacological manipulations, suggesting an inverted-U function resembling the Yerkes-Dodson Law, possibly linked to tonic and phasic dopaminergic transmission.

DEFINING CREATIVITY ON THE EDGE OF CHAOS FOR COGNITIVE AND BIOLOGICAL RESEARCH

Creative works may be defined as combining novelty (or originality) and utility (or effectiveness, or value) within the domain from which they emerge (Runco and Jaeger, 2012). We relate this to the ideas of Stuart Kauffman, who highlighted the importance of production "on the edge of chaos" to yield valuable change in self-organizing systems spanning thermodynamic, economic, and biochemical systems (such as those involved in the origins of life) (Kauffman, 1993, 1995). Kauffman argues that these systems can be characterized by the predictability of their components. Considering elements within complex systems, some are "orderly" (predictable, redundant) while others are more "chaotic" (unpredictable, entropic). Kauffman sees new and useful developments as emerging "on the edge of chaos," the boundary between ordered and chaotic regimes.

The Edge of Chaos theory can be applied to cognitive processes and brain activation states important for creative cognition. Considering the diversity of possible cognitive states, we can differentiate the highly predictable and orderly from the unpredictable and chaotic. In more chaotic regimes, network states are more disconnected from those in the ordered regime. But "at the edge of chaos," the states are maximally novel while still connected to states in the ordered regime, and thus are most likely to manifest the combination of novelty and utility that is the hallmark of creativity. A similar conceptual approach was used to distinguish "rigidity," "chaos," and "integration" to characterize semantic network states in people with Asperger's syndrome, schizophrenia, and healthy semantic processing, respectively (see Faust and Kenett, 2014 for good graphical models; see also Siegel, 2010; Kaufman, 2014 for additional examples).

The theory of evolutionary cytoarchitectonic trends may provide an anatomic and neuropsychopharmacologic substrate for these cognitive dimensions, with complementary systems that increase the stability or flexibility of cognitive states via the archicortical and paleocortical trends, respectively (Christensen and Bilder, 2000; Bilder, 2012). Local cortical networks employ the complementary actions of tonic and phasic dopamine signaling, which putatively mediate stability and flexibility, respectively (Bilder et al., 2004); similarly, D1- and D2-like dopamine transmission may mediate persistence or updating within cell assemblies (Durstewitz and Seamans, 2002). Others have emphasized noradrenergic mechanisms to achieve similar network dynamics (McClure et al., 2006). We believe this view advances conceptualization of the role of DA in creative cognition beyond models in which DA was suggested to have a unitary function by facilitating "working memory" or "mental associations" (Flaherty, 2011), or "flexibility" as manifest in higher-order personality traits (DeYoung, 2006).

This theory may help provide a neural systems basis for the theory that creativity results from Blind Variation and Selective Retention (BVSR) (Campbell, 1960; Simonton, 2011a,b). Assuming that blind variation relies on "flexibility" while selective retention relies on "stability,"

then our theory has multiple implications: (a) the neural system basis for "sighted" vs. "blind" variations is synaptic facilitation governing the likelihood that a given network activation state will be stabilized and more likely to re-occur; (b) the "unit of analysis" upon which blind variation operates was first stated as a "thought trial" (Campbell, 1960); Simonton refined this to be the "ideational variant"; we suggest that BV operates on the "perception-action cycle," with a frequency of about 3 Hz, approximately how long it takes to compare a stimulus to expectations; and (c) we distinguish systematic from stochastic variation, with the systematic approach engaging cognitive control (task positive networks), while the stochastic approach disengages cognitive control and engages default mode networks.

THE EDGE OF CHAOS, CREATIVITY, AND MENTAL HEALTH

How do these ideas relate to the theme of this issue: *creativity and madness*? We suggest the link between creativity and mental illness can benefit from considering the stability and flexibility of cognitive states. For example, Martin Paulus and colleagues used a two-choice guessing paradigm to calculate the entropy of sequential responses made by people with schizophrenia (Paulus et al., 1999). In this paradigm, people "guess" which of two alternatives (e.g., "left" or "right") will occur next, when in fact the order of outcomes is random. We can analyze the sequence of guesses and quantify their entropy (unpredictability). Healthy people tend to have a Gaussian distribution of sequential guesses, with most responses at intermediate levels of entropy, and fewer very redundant or very entropic responses. In contrast, people with schizophrenia tended to show both more redundant (predictable) and more entropic (unpredictable) responses; longer periods of predictable behavior were interrupted by very unpredictable behavior. We showed that the entropy of responses is linked to dopamine (DA) dynamics; specifically we found that DA "tone" (the balance of agonism to antagonism) had an "inverted-U" association with predictability of responses (Bilder et al., 1992). These examples highlight that the *balance* of stability and flexibility is critical to maintain optimal, healthy function.

The Edge of Chaos theory is also compatible with the neural network frameworks that Ralph Hoffman, Stephen Grossberg, and their colleagues have used to describe schizophrenia (Hoffman and Dobscha, 1989; Grossberg, 1999, 2000; McGlashan and Hoffman, 2000). Either widespread dysconnectivity or impairment of dopamine dynamics governing the stability and flexibility of neural network activation states can lead a network to get "stuck" in a local energy minimum (thus explaining abnormal predictability), but when the activation state does shift, the new state is likely to be more "distant" and less "connected" to the preceding state (thus explaining abnormal unpredictability).

We believe this model conforms with the inverted-U model relating creativity with psychopathology traits and genetic risk for psychosis (Richards et al., 1988) and with existing literature showing examples of exceptional creativity in individuals with mental illness, even though the aggregated results tend to show no overall increase in creative achievement for those with severe mental illness (Rothenberg, 1983; Eisenman, 1990; Abraham et al., 2007; Jaracz et al., 2012). Consistent reports suggest that healthy relatives of those with schizophrenia, and those with schizotypal traits, may have elevated creativity; we suggest that these individuals may have a tendency to greater network flexibility, but additional traits help protect them from developing schizophrenia (Schuldberg, 2000; Kinney et al., 2001; Karimi et al., 2007; Abraham and Windmann, 2008; Batey and Furnham, 2008; Nelson and Rawlings, 2010). Consistent with this are Kinney et al. (2001) results showing higher levels of creativity in people with intermediate levels of schizotypal or schizoid traits, relative to those with lower levels of these traits *and* relative to those with overt schizophrenia.

Evidence about bipolar disorder is less clear, but empirical studies show similar inverted-U distributions: a milder degree of mood disorders, bipolar temperaments, or genetic liability (without full-blown bipolar disorder) may be linked to increased creative achievement, but more severe illness is not. For example, children with pediatric bipolar disorder perform worse on tests of set-shifting or cognitive flexibility (Gorrindo et al., 2005; Dickstein et al., 2007), and while adults with bipolar disorder may have increased inventiveness, scores are lower during depressive episodes (Rybakowski and Klonowska, 2011). Richards et al. (1988) also reported that participants with cyclothymia, and healthy first-degree relatives of patients with bipolar disorder, had higher lifetime creativity scores compared to patients with bipolar disorder and healthy controls with no family history of major affective disorder or schizophrenia. Similarly, researchers found that hypomanic (Furnham et al., 2008) or hyperthymic traits in healthy individuals (Shapiro and Weisberg, 1999) were significantly correlated with measures of creativity. Overall, the data suggest that hereditary risk (without severe impairment), and/or moderate subclinical variations of bipolar disorder or schizophrenia may be associated with enhanced creative achievement, while the more severe forms of these syndromes are associated with impairments of creativity, paralleling impairments in other cognitive processes.

With respect to the evolutionary advantages, Kauffman wrote:

> "If it proves true that selection tunes genomic systems to the edge of chaos, then evolution is persistently exploring networks constrained to this fascinating ensemble of dynamical systems (Kauffman, 1993, p. 522)."

We suggest that the underlying genomic systems, and their systems biology correlates at the level of neural network activation states, are tuned to the edge of chaos, helping explain both the observed associations *and dissociations* of creativity with mental illness.

These assumptions are consistent with the hypothesis that neural network dynamics associated with cognitive flexibility are linked to creative achievement because these dynamics generate activation states that are novel with respect to population averages, and favor performance on metrics that are tuned to *divergent thinking* (problem-solving processes that involve exploring multiple

alternative solutions). But if the dynamics proceed too far in the direction of flexibility, entropy, and unpredictability, then cognitive products may be novel and unpredictable, but may be "over the edge of chaos," and not be perceived as useful, valuable, or effective.

IMPLICATIONS FOR MENTAL HEALTH AND PROMOTING CREATIVE ACHIEVEMENT

The Edge of Chaos hypothesis may help understand the pathophysiology and treatments of mental illness, and suggest paths to augment creativity. We can assess positive traits of cognitive stability and flexibility (or disadvantageous traits: rigidity and lability), and determine their relations with cellular and neuromodulatory factors. For example, widespread dysconnectivity and DA dysregulation remain candidates in the pathophysiology and treatment of schizophrenia. To the extent that interventions impact these states, monitoring stability/flexibility may be beneficial in determining when treatments are managing chaotic (overly flexible) states but not causing cognitive rigidity. For example, measures of network stability/flexibility could help titrate treatments in schizophrenia to maximize freedom from positive symptoms while minimizing cognitive impairment, or titrate the DA and norepinephrine reuptake inhibition in Attention Deficit/Hyperactivity Disorder (ADHD) to maximize attentional control.

Non-pharmacological treatments might someday be tuned to optimize flexibility and stability. For example, EEG neurofeedback strategies emphasizing cognitive stability or flexibility may enhance creativity (Gruzelier, 2014; Gruzelier et al., 2014a,b; but see also Schaller et al., 2013). Slow cortical potential neurofeedback training may enhance stability and benefit those with ADHD (Monastra, 2008; Studer et al., 2014). Transcranial magnetic stimulation or direct current stimulation may also moderate cortical stability and flexibility (Nitsche et al., 2009). TDCS studies already have shown enhancements of creative thinking (Chi and Snyder, 2011; Metuki et al., 2012; Chrysikou et al., 2013; but see also Ghacibeh et al., 2006).

There are further links of cognitive stability and flexibility to meditation practices referred to as focused attention and open monitoring, respectively (Lutz et al., 2008a,b; Slagter et al., 2011). We are not aware of studies showing enhanced creativity among Buddhist monks, but other studies already have shown a positive impact of meditation practices on divergent thinking (Horan, 2009; Colzato et al., 2012). In the future, assessment of individual differences in baseline stability and flexibility might lead to prescriptive contemplative practices. These approaches already have gained traction in the management of anxiety by broadening of attention using mobile phone applications (Enock et al., 2014), and we anticipate the future will deliver additional tools to manage brain activation states, perhaps combined with personal EEG devices.

In conclusion, we believe that understanding both mental illness and creative cognition from the perspective of neural network dynamics, and specifically the regulation of the stability and flexibility of cortical activation states, helps to clarify the relation between creativity and mental illness. We further believe understanding these cognitive dynamics may have profound implications for both understanding of pathophysiology of mental illness, the development of novel intervention strategies for those who are ill, and the enhancement of creative cognition more broadly across the population.

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Creativity and schizophrenia spectrum disorders across the arts and sciences

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> *"There is only one difference between a madman and me. I am not mad."*
> *—Salvador Dali*

Researchers agree that mental illness is neither necessary nor sufficient for creativity. But is there still a significant link between the two?

The oft-cited studies by Jamison (1989), Andreasen (1987), and Ludwig (1995) showing a link between mental illness and creativity have been criticized on the grounds that they involve small, highly specialized samples with weak and inconsistent methodologies and a strong dependence on subjective and anecdotal accounts (Schlesinger, 2009).

To be sure, research does show that many eminent creators—particularly in the arts—had harsh early life experiences (such as social rejection, parental loss, or physical disability) and mental, and emotional instability (Ludwig, 1995, 1998; Simonton, 1994). However, this does not mean that mental illness was a contributing factor to their eminence. There are many eminent people without mental illness or harsh early life experiences, and there is very little evidence suggesting that clinical, debilitating mental illness is conducive to productivity and innovation.

What's more, only a few of us ever reach eminence. Beghetto and Kaufman (2007) argue that we can display creativity in many different ways, from the creativity inherent in the learning process ("mini-c"), to everyday forms of creativity ("little-c") to professional- level expertise in any creative endeavor ("Pro-c"), to eminent creativity ("Big-C").

Engagement in everyday forms of creativity (Richards, 2007)—expressions of originality and meaningfulness in daily life—certainly do not require suffering. Quite the contrary, people who engage in everyday forms of creativity—such as making a collage, taking photographs, or publishing in a literary magazine—tend to be more open-minded, curious, persistent, positive, energetic, and intrinsically motivated by their activities (Ivcevic, 2007; Ivcevic and Mayer, 2009). Those scoring high in everyday creativity also tend to report feeling a greater sense of well-being and personal growth compared to their classmates who engage less in everyday creative behaviors.

Creating can also be therapeutic for those who are already suffering. For instance, research shows that expressive writing increases immune system functioning (Kaufman and Sexton, 2006; Kaufman and Kaufman, 2009), and the emerging field of posttraumatic growth is showing how people can turn adversity into creative growth (Tedeschi and Calhoun, 2004; Forgeard, 2013).

That said, there is a grain of truth to the notion that creativity and mental illness are related, but the truth is much more nuanced—and we think interesting—than the more romanticized notions of the link.

To see the matter clearly, we need to take a step back and consider what we mean by "creativity" and "mental illness" in the first place. While there are many forms of mental illness, this paper focuses on schizophrenia, a mental disorder characterized by a severe disconnect from reality, including a tendency to experience thoughts that are divergent, disorganized, and delusional. One aspect of creativity is obviously novelty or originality. Schizophrenic thoughts are more likely to be unique or new. So, by its very nature, schizophrenia disposes one toward satisfying one requirement for creative thought: namely originality.

Originality is not sufficient for creativity, however, for as Kant (2000) observed long ago, "there can be original nonsense," as in the word salad of a schizophrenic patient. For a product to be creative it must not only be new but also useful, effective, or valuable in some way (Sternberg and Lubart, 1999; Gaut, 2010; Klausen, 2010). A highly original product might be deemed a symptom of mental illness or an expression of creativity depending on whether or not it is useful. Creativity is maximized when both novelty and utility are simultaneously maximized.

These two features—novelty and utility—respectively depend on two cognitive functions: the *generation* of ideas popping up in conscious thought, and the *selection* of ideas to be explored, developed, and ultimately expressed or realized in the form of an observable product (cf. Finke et al., 1992). These two cognitive functions map nicely onto the Blind Variation and Selective Retention (BVSR) model of creativity (Campbell, 1960; Simonton, 2011; Jung et al., 2013; Jung, 2014).

The more productively one *generates* ideas (regardless of the extent to which

the utilities are initially known), the more likely some of them will be new. The more effectively one *selects* and develops particular ideas, the more likely some of them will result in something useful. Being creative is similar to mental illness in that it involves a heightened capacity and inclination to produce a large quantity of ideas and associations. What distinguishes the creative person is that she is better able to manage the flood of ideas, selecting the useful ones and developing them effectively while discarding the others. This chimes with the oft-quoted remark of scientist, peace activist, and two-time Nobel laureate Linus Pauling: "The way to get good ideas is to get lots of ideas and throw the bad ones away."

Indeed, recent research suggests a link between milder forms of schizophrenia and creativity. In a recent report based on a 40-year study of roughly 1.2 million Swedish people, Kyaga et al. (2013) found that those in scientific and artistic occupations were *not* more likely to suffer from psychiatric disorders, with the exception of bipolar disorders. So full-blown mental illness did not increase the probability of entering a creative profession (even the exception, bipolar disorder, showed only a small effect of 8%).

What was striking, however, was that the *siblings* of patients with autism and the *first-degree relatives* of patients with schizophrenia were significantly overrepresented in creative professions. Could it be that the relatives inherited a watered-down version of the mental illness conducive to creativity while avoiding the aspects that are debilitating?

Research shows that psychologically healthy biological relatives of people with schizophrenia have unusually creative jobs and hobbies and tend to show higher levels of schizotypal personality traits compared to the general population (Karlsson, 1970; Kinney et al., 2001). Schizotypy consists of a constellation of personality traits that are evident to some degree in everyone.

Schizotypal traits can be broken down into two types. "Positive" schizotypy includes unusual perceptual experiences, thin mental boundaries between self and other, impulsive nonconformity, and magical beliefs. "Negative" schizotypal traits include cognitive disorganization and physical and social anhedonia (difficulty experiencing pleasure from social interactions and activities that are enjoyable for most people). Nettle (2006) found that people with schizotypy typically resemble schizophrenia patients much more along the positive schizotypal dimensions (such as unusual experiences) compared to the negative schizotypal dimensions (such as lack of affect and volition).

This has important implications for creativity. Batey and Furnham (2008) found that the unusual experiences and impulsive nonconformity dimensions of schizotypy, but not the cognitive disorganization dimension, were significantly related to self-ratings of creativity, a creative personality (measured by a checklist of adjectives such as "confident," "individualistic," "insightful," "wide interests," "original," "reflective," "resourceful," "unconventional," and "sexy"), and everyday creative achievement among thirty-four activities ("written a short story," "produced your own website," "composed a piece of music," and so forth).

Recent neuroscience findings further support the link between schizotypy and creative cognition. Takeuchi et al. (2011) investigated the functional brain characteristics of participants while they engaged in a difficult working memory task. Importantly, none of their subjects had a history of neurological or psychiatric illness, and all had intact working memory abilities. Participants were asked to display their creativity in a number of ways: generating unique ways of using typical objects, imagining desirable functions for ordinary objects and imagining the consequences of "unimaginable things" happening.

The researchers found that the more creative the participant, the more they had difficulty suppressing the precuneus while engaging in an effortful working memory task. The precuneus is the area of the Default Network (Buckner et al., 2008; Jung et al., 2013; Andrews-Hanna et al., 2014) that typically displays the highest levels of activation during rest (when a person is not focusing on an external task). The precuneus has been linked to self-consciousness, self-related mental representations, and the retrieval of personal memories (Cavanna and Trimble, 2006). How is this conducive to creativity? According to the researchers, "Such an inability to suppress seemingly unnecessary cognitive activity may actually help creative subjects in associating two ideas represented in different networks."

Whitfield-Gabrieli et al. (2009) found a similar inability to deactivate the precuneus among schizophrenic individuals and their relatives. Which raises the intriguing question: what happens if we directly compare the brains of creative people against the brains of people with schizotypy?

A recent study by Fink et al. (2014) sheds some light on this question. Consistent with earlier research, they found an association between the ability to come up with original ideas and the inability to suppress activation of the precuneus during creative thinking. As the researchers note, these findings are consistent with the idea that more creative people include more events/stimuli in their mental processes than less creative people. But crucially, they found that those scoring high in schizotypy showed a similar pattern of brain activations during creative thinking as the highly creative participants. This supports the idea that overlapping mental processes are implicated in both creativity *and* psychosis proneness.

Therefore, it seems that the key to creative cognition is opening up the flood gates and letting in as much information as possible. Because you never know: sometimes the most bizarre associations can turn into the most productively creative ideas. This idea is consistent with recent research on latent inhibition (Kaufman, 2009). Latent inhibition is a filtering mechanism that we share with other animals and it is tied to the neurotransmitter dopamine (Lubow and Weiner, 2010). A reduced latent inhibition allows us to treat something as novel, no matter how many times we've seen it before and tagged it as irrelevant.

Prior research shows a link between reduced latent inhibition and acute-phase schizophrenia (Baruch et al., 1988a,b; Lubow et al., 1992). But more recent research also shows a link to creativity. Carson et al. (2003) found that the most eminent creative achievers among a sample of Harvard undergrads were seven times more likely to have reduced latent inhibition. As Carson (2011) points

out in her "Shared Vulnerability Model," mental processes such as reduced latent inhibition, preference for novelty, and hyperconnectivity can "enlarge the range and depth of stimuli available in conscious awareness to be manipulated and combined to form novel and original ideas" (p. 144). Extreme levels of these factors make one vulnerable to severely disordered thinking. But they can be mitigated and channeled productively if one has *protective factors*, such as enhanced fluid reasoning, working memory, cognitive inhibition, and cognitive flexibility (Kuszewski, 2009; Carson, 2011).

Another protective factor may lie within the openness to experience domain, a broad personality domain reflecting the tendency toward cognitive exploration (DeYoung, 2014). Peterson and Carson (2000) and Peterson et al. (2002) found that students with reduced latent inhibition scored higher in openness to experience. But while openness to experience is consistently associated with creativity (see Kaufman, 2013, Kaufman et al., submitted), this personality domain can also be meaningfully separated into distinct (but correlated) subtraits of *Openness to Experience* and *Intellect* (DeYoung et al., 2007; DeYoung, 2014).

Openness to Experience reflects cognitive engagement with sensory and perceptual information, whereas *Intellect* reflects cognitive engagement with abstract and semantic information, primarily through reasoning. While Intellect is associated with IQ, executive functioning, and intellectual engagement, Openness is associated with fantasy-proneness, schizotypy, absorption, delusional ideation, and the tendency to make connections and see patterns that don't actually exist (DeYoung et al., 2012; Kaufman, 2013; Menon et al., 2013; Chmielewski et al., 2014). Indeed, Intellect is negatively associated with positive schizotypy and delusional ideation (Menon et al., 2013).

Therefore, the combination of Openness and Intellect may be crucial to maintaining high levels of creative production (DeYoung et al., 2012). The proper balance most likely differs by domain. There is emerging evidence across diverse samples, ages, and occupations that Openness is associated with creative achievement in the arts, whereas Intellect is associated with creative achievement in the sciences (Kaufman, 2013; Kaufman et al., submitted). This is consistent with research suggesting that schizotypy is associated with verbal and artistic creativity (Del Giudice et al., 2010; Beaussart et al., 2012) whereas the autism spectrum is associated with technical-scientific interests and careers (Baron-Cohen et al., 2001; Crespi and Badcock, 2008).

Nevertheless, recent research suggests that creative cognition draws on both the executive functioning that is tied to Intellect and the associative divergence that comes with Openness (Nusbaum and Silvia, 2011; Beaty et al., 2014; Benedek et al., 2014; Jung, 2014). Being susceptible to schizophrenia spectrum disorders may enhance Openness, increasing the likelihood of ideas that are original. To develop ideas that are creative, however, one also needs protective intellectual factors (and autistic-like traits) to steer the chaotic storm.

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