CHALLENGES OF INTERDISCIPLINARY RESEARCH IN THE FIELD OF CRITICAL (SEX/ GENDER) NEUROSCIENCE

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CHALLENGES OF INTERDISCIPLINARY RESEARCH IN THE FIELD OF CRITICAL (SEX/ GENDER) NEUROSCIENCE

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EDITORIAL
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Editorial: Challenges of Interdisciplinary Research in the Field of Critical (Sex/Gender) Neuroscience

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Editorial on the Research Topic

Challenges of Interdisciplinary Research in the Field of Critical (Sex/Gender) Neuroscience

There is currently widespread agreement among scholars that neuroscientific investigations that purport to delineate sex- and gender-related structural and functional brain differences urgently require conceptual critique, methodological nuance and thorough reflexivity about the research questions, operationalization, interpretations and implications shaping this scholarship (Fausto-Sterling, 2000; Fine, 2010; Jordan Young, 2010; Roy, 2012). In response to this need, the seven articles in this collection demonstrate new avenues in critical interdisciplinary scholarship in the field of sex/gender and neuroscience research, including approaches that draw on feminist science studies and critical neuroscience. Since the first publications that show how social and cultural values pervade the formulation of biological research on sex and gender, enormous developments have also occurred in the neurosciences, with increased evidence from functional neuroimaging and epigenetics pointing to the context-sensitivity and contingencies of brain development and function. This underscores the imperative for researchers to consider carefully their treatment of difference and of their conceptions of complexity and diversity. It is clear that we need to work out how to collaborate across epistemic boundaries, how to refine and draw on social theory to make sense of brain findings and how together this can inform interpretation of experimental data, data that bear relevance to the real world.

This Frontiers research topic builds on a key insight by critical feminist scholars: to arrive at a critical and more socially just production of knowledge about human behaviour it is important to go beyond the split between second order and first order observations, i.e., between critical sociological observations about neuroscientific practice and experimental investigations of the brain. Investigating and responding (to) this goal, the studies in this collection show how, in varying ways, scientific disciplines newly interact and may also clash in the formation of new conceptualizations of the relation between gender, sex and the material brain. The collection thus contributes to a better understanding of inter- or multi-disciplinary relations necessary to advance a study of the brain and human behaviour that is crucially informed by a feminist agenda. Moreover, improving our knowledge of (inter-)disciplinary epistemic dynamics by means of the specific case studies in this collection also offers background to an ongoing discussion about how to realize intersectional research.

The past 2 decades saw the emergence of a number of sub-(inter-)disciplinary labels and scholarly networks such as "critical neuroscience" (Choudhury and Jan, 2012, Kirmayer and Crafa, 2014), "neurofeminism" (Roy, 2008; Bluhm et al., 2012; Schmitz and Höppner, 2014), "neurogenderings" (Dussauge and Kaiser, 2012; Fitsch, 2012) and "neurocultures" (Schmitz and Höppner, 2014; Vidal and Ortega, 2018), as examples of the heterogeneous bodies of knowledge and gatherings of scholarship (sometimes converging, sometimes conflicting) that aim to analyse fundamental

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assumptions and particular biases in, as well as social, political and cultural contexts of, neuroscientific research and to address how studies of the body and the brain shape narratives about human behaviour, including gender difference (Kraus, 2012; Roy, 2012, 2016; Rippon et al., 2014; Kuria, 2014; O Connor and Helene, 2014; Joel and Fausto-Sterling, 2016; Bentley et al., 2019; Lockhart, 2020).

The current collection of articles builds on 2 decades of experimenting with forms of disciplinary collaboration in the examination of sex/gender and the brain (Fausto-Sterling, 2000) and takes important cues from scholars who have critically interrogated and problematized the hopes and forms of engagement attached to the buzzword "interdisciplinarity" (Callard and Fitzgerald, 2015). The question of interdisciplinarity–if and how scholars in the social sciences, humanities and biosciences should interact, inform, scrutinize or collaborate (with) one another to accomplish more nuanced and just articulations of biosociality–has been a longstanding and integral issue for (feminist) science and technology studies scholars, and a central challenge for critical neuroscientists, neurofeminists and other feminist (neuro-) science studies scholars of the brain and human cognition. In the past decade, feminist scholars have proposed new tools, models and experimental designs to generate more refined and socially just bio-socio-cultural perspectives in contemporary neuroscience. These researchers hotly contest sex/gender binaries in brain science (Joel, 2011; Schmitz and Höppner, 2014; Joel and Fausto-Sterling, 2016; Cornel, 2019; Walsh and Einstein, 2020; Eliot et al., 2021) and scrutinize the technological and statistical tools used in mapping sex/gender differences (Bryant et al., 2019; Sanchis-Segura et al., 2020; Duchesne et al., 2020; Eliot et al., 2021; Fitsch et al., 2020).

In a moment in which debates around the role of biology in relation to sex and gender is especially fraught, and indeed a moment in which the climate of debate within and beyond academia are particularly polarized, this conversation warrants particular reflexivity. Our goal in this issue is to invite views on what kinds of creative investigation may be most appropriate to address the question and unsettle existing assumptions (Fine, 2010), and the methodological challenges and potential they give rise to. Feminist neuroscientists have asked new, not purely binary, questions to data (Joel, 2011; Kaiser, 2012; Shattuck-Heidorn and Richardson, 2019; Eliot, 2020) and have come up with new models, such as the mosaic brain (Joel et al., 2015). Along with the critical examination of the apparatus of neuroscience, another important intervention into current practices of neuroscience is the work of feminist, queer and critical race studies scholars that raise issues of epistemic justice–of excluded bodies of knowledges and marginalized subjects, and rally for a "science from below" (Harding, 2008). A call for scholarship that works with people affected by the outcome, rather than studies that are about subjects, is prominent in disability studies, mental health and intersex/trans studies, in which the framework of epistemic justice has renewed the debate over critical studies of the normal and the pathological (Annamma et al., 2013; Baril, 2015; LeBlanc and Kinsella, 2016; Tremain, 2017). A third important development has come from scholars in (or partly affiliated to) critical race studies, who have generated renewed attention to colonial practices of (mis)measurements, surveying and administration of the marginalized (Heinz et al., 2014; Abiodun, 2019; Black in Neuro, 2021; Rollins, 2021b; Moody, 2021); have called for a decolonization of classificatory systems in neuroscience (Birhane and Guest, 2020); and emphasize the importance of developing a critical, intersectional perspective in accounts of humans in their environment (Alexander-Floyd, 2012; Collins and Bilge, 2020; Cole, 2020; Shields, 2008), including the study of sex/gender and the brain and relatedly, a critical perspective on institutional practices in neuroscience, including citation practices and grantee demographics (Choudhury and Neil, 2020; Dworkin et al., 2020). However, in spite of these significant sociologically-informed theoretical and methodological recommendations by feminist, queer and critical race studies scholars, such proposals are still under-used or haphazardly implemented in studies of the neuroscience of sex and gender.

Different figures or frameworks of disciplinary relationships have been in circulation: for example, the possibility of a more "critical friendship" between the social sciences/humanities and the life sciences to advance a non-reductionist articulation of human beings and other organisms in their milieu (Rose, 2013); or the call for a "dissensus studies" into sex/gender neuroscience, by which social scientists do not sidestep scientific controversy but exacerbate political matters by paying particular attention to social conflicts in relation to brain research (Kraus, 2016).

In the spirit of a call for "a more expansive account of human development and subject formation" (Frost, 2017), the papers in this collection demonstrate and critically analyse novel interdisciplinary relations to advance feminist and critical neuroscientific scholarship, examining fields ranging from fMRI research, brain-computer-interfaces and cyborgization, intersectionality in feminist psychology, infant gender/sex identity development, to brain studies of (trans)gender identity, neuro-epigenetics and trauma, and understandings of translational neuroscience literature on epigenetics.

SEVEN ANALYSES OF INTERDISCIPLINARITY IN THE STUDY OF SEX/GENDER AND THE BRAIN

20 years ago, Anne Fausto Sterling, contributor to the present collection of articles, predicted that cognitive scientists would have absorbed the important scholarship of feminist neuroscience into their research programs. "We will no longer be debating about male *versus* female brains or arguing that men are better than women at reading maps (. . .)." Writing in her seminal 2000-study *Sexing the Body*, she argued the way forward would be to create "non-hierarchical, multidisciplinary teams" to create awareness of the inevitable limits of disciplinary knowledge (Fausto-Sterling, 2000). Today, after two decades of path-breaking feminist advances in sex/gender research in the neuro- and life-sciences, it is clear that there is still much work to be done (Rippon et al., 2014; Bryant et al., 2019; Eliot et al., 2021).

In her contribution to this *Frontiers* collection of articles, Anne Fausto Sterling continues to emphasize the importance of designing interdisciplinary consortia that offer a meeting ground for insights from gender studies, neuroscience, physiology, developmental psychology and cognitive development. Based on extensive data analysis and literature review, her study proposes a multi-level, dynamic, and developmental systems theory of early gender/sex identity development and she discusses the challenges of understanding how infants integrate events that occur on different time scales and at different levels of biological integration. This theoretically-informed multi-level project can only be advanced, Fausto-Sterling argues, if researchers develop skills in interdisciplinary conversations and when they shape an emergent (not an additive) form of collaboration. Researchers need "to figure out how to draw conclusions that translate across levels of organismic organization (and disciplinary boundaries)".

In their contribution for this collection, Lawson-Boyd and Meloni point to the need for more cross-disciplinary dialog in order to advance new perspectives on neuro-epigenetics. After an analysis of literature in the converging fields of neuro-epigenetics, sex/gender and trauma (with a particular focus on the work of feminist STS scholars), the authors evaluate a number of qualitative interviews they conducted with neuroscience and biology researchers in epigenetics and reflect on their interviewee' knowledge of-and engagement with problems raised by feminist STS scholars. Lawson-Boyd and Meloni conclude that while scientists working in neuro-epigenetics have themselves raised the need for a reorientation of the field, they still have to take (more) knowledge from beyond the biosciences into account. If the aim (in the case of this field of scholarship) is to better understand and to ultimately reduce stress levels in mothers, a vital step, the authors argue, is a parallel analysis of "difference (and sameness) on the scales of neurophysiology and sociality." This can only be done when researchers are willing to experiment with novel methodologies and when neuroscientists, molecular biologists and social scientists "speak candidly and respectfully with one another."

The article by Norrmén-Smith et al. in this collection casts another perspective on the field of epigenetics, examining the impact of neurobiological and epigenetic framings of motherhood on pregnant women and new mothers. Based on detailed analysis of focus group data, they argue that the engagement of women with biomedical and cultural perinatal information on the internet and social media–for example, the discussion of the imprinting of mothers' experiences on their prenatal baby's DNA–has the potential to exacerbate emotional distress and to impact women's experience, self-construal and wellbeing. The authors' approach in this article is to bring a critical neuroscience-informed discourse analysis of neuroscience literatures around maternal and infant health together with qualitative analysis of focus group data about how consumers make sense of epigenetic and neuroscientific information and its looping effects. By taking this dual approach, the authors are careful not to overstate the transformative potential of popular neuroscientific rhetoric around plasticity and risk, but to study more closely how such information about brain-based susceptibility is interpreted and affects mothers. They demonstrate that while the appeal of neuroscience is often its state-of-the-art objectivity and novelty, it often ends up reinscribing the same social and moral dilemmas of older discourses, responsibilizing mothers in particular ways.

The articles by Schmitz and Fitsch in this collection emphasize the heterogeneity and interdisciplinary dynamics that are integral to the discipline of neuroscience itself. With a feminist STS-oriented discursive analysis, Schmitz examines current visions of transhumanism and the way these normative, discriminatory imaginaries of (the governing of) life are shaped and authorized by a body of neuroscientific research into brain-computer interfaces as well as discourses on neuro-technical developments. Paying attention to moments of inconsistency and recalcitrance in these systems, she proposes an alternative, more socially just articulation of "cyborgization." The concept of cyborgization is meant to tackle the white, middle class, male rhetoric of grandiosity and modern neurobiological determinism and "the effects of neuro-technological and transhumanist governmentality on the question of whose lives are to be improved and whose lives should be excluded from these developments."

Fitsch examines binary sex/gender categorization in magnetic resonance tomography and discusses empirical methodologies and epistemic underpinnings of differentiation through statistics. She argues that "counter-counting", weighing and sizing is not helpful to substantiate the idea of "equality" (not only for sex/gender) in brain studies. The author asks for situated interdisciplinarity as "a scaffold" for intersectionality, to get epistemes, techniques and new methods on categorizing and differentiating in brain modelling into view. Referring to the topic of this special issue, this paper argues that for an interdisciplinary approach to criticize dimorphism and differentiation by groups, we need a broader understanding of the technical and theoretical foundations used in brain research.

Llaveria Caselles article for this collection points to the lack of interdisciplinary practices for advancing the study of (trans) gender identity. Llaveria Caselles employs the framework of epistemic injustice to analyse literature on brain studies of (trans)gender identity and to conduct an ethnomethodological study into the epistemic behaviours and attitudes of researchers involved in this field. In his article, Llaveria Caselles operationalizes "epistemic friction" by asking researchers about alternative, counter-hegemonic approaches to the study of (trans) gender. Llaveria Caselles identifies a lack of sensitivity towards biosocial, developmental, mosaicist, contextualist, and depathologizing research avenues and demonstrates the exclusion of counter-hegemonic practices and of epistemic agents associated with alternative approaches. He alludes to the way that systemic factors related to the organization of scientific work (such as the projectification of science) contribute to the privileging of "normal science" over revolutionary or risky science. To work towards a better and more just study of transgender identity, he recommends a number of strategic epistemic practices, including the "promotion of exchange across disciplines" and building inter- and transdisciplinary networks.

Llaveria Caselles' study also points to the value of ethnomethodological research into the epistemic practices that foster or hinder intersectional approaches. Taking intersectionality seriously in the field of neuroscience means that researchers have to develop comprehensive analyses that include the tangled impacts and lived experiences of, for example, disability, race, sexuality, age, and class. Llaveria Caselles' interviews with brain researchers demonstrate the problems of attending to intersectionality in experimental practice. One researcher pointed to the infeasibility of analysing how race, gender identity and context of upbringing interact with each other and affect brain development. Other reactions demonstrated misunderstanding of the concept of intersectionality all together. Overall, Llaveria Caselles concludes that researchers experienced "difficulties in moving away from a paradigm of clear categories, as well as the tendency to focus on biological and quantifiable factors."

The issue of intersectionality is central to the final contribution to this collection, in which Duchesne and Kaiser Truijillo analyse how neurofeminist scholars may learn from intersectional approaches in feminist psychology scholarship. They point to three potentially valuable "research programs" in intersectional research in psychology literature and assess their value for feminist neuroscience. Duchesne and Kaiser Truijillo also address the problem of the gradual de-politicization and neutralization of (some versions of) intersectional research (away from the social justice-oriented change) and the move away from addressing the specific intersectional position of Black women. One potential means of addressing these issues in relation to the study of intersectionality, the authors argue, is to articulate the positionality of the authors and author's scholarly relation to the intersectional objective of social justice. Again, understanding dynamics of disciplinary relations can help to advance an intersectional, feminist study of sex/gender and the brain.

CONCLUSION

The articles in this collection provide the grounding for critical reflection on interdisciplinary approaches to sex/gender and the brain through various analytical examples from a range of scholarly backgrounds. Another outcome of this collection is that a number of contributions address–as part of a consideration of advancing novel forms and methodologies-the possibility and difficulties in conceptualizing and practicing intersectional approaches to the study of sex/gender and the brain. A closer look at inter-disciplinary, multi-disciplinary and trans-disciplinary research supports a more nuanced framework for the way ideas and methods can be drawn together to support such an intersectional approach. Key, in this respect, as various authors in this collection have mentioned, is attending to the interplay of various kinds of positionalities and embodiments to do justice to the plurality and complexity of human experience and to question practices of categorization.

In this vein, sociologist Oliver Rollins has recently argued that to gain a better understanding of under-examined practices of racialization in neuroscience, it is necessary to connect macro- and micro-level practices and to bring neuroscientific scholarship in conversation with social policy scholarship and to attend to the way neurobiological calculations may erroneously omit racial experiences or instead inadvertently encode normative ideas about racial worth (Rollins, 2021a; 2021b).

An interdisciplinary approach not only needs to open for other disciplinary perspectives, but also for new practices. Llaveria Caselles, in this collection, aligns his scholarly work with counter-hegemonic positions and calls for "interventionist projects" in knowledge production. Similarly, Lawson-Boyd and Meloni "urge scientists to consider what allowances and restrictions any positioned perspective offers." Again, demands for other ways of doing science, are not new (Rose and Rose, 1979; Haraway, 1988). Some of these former calls should be reinvestigated to invigorate current approaches, to arrive at intersectional neuroscience and to improve our understanding of the interplay between science and society.

AUTHOR CONTRIBUTIONS

FL and HF conceptualised and drafted the editorial. SC provided conceptual input to the manuscript and editorial revisions. All co-authors contributed to the writing of the editorial.

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Epistemic Injustice in Brain Studies of (Trans)Gender Identity

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This study undertakes an analysis of the conceptualization of gender identity in neuroscientific studies of (trans)gender identity that contrast the brains of cisgender and transgender participants. The analysis focuses on instances of epistemic injustice that combine scientific deficiencies and the exclusion of relevant bodies of knowledge. The results of a content analysis show how the ignoring of biosocial, developmental, mosaicist, contextualist, and depathologizing approaches leads to internal conceptual inconsistencies, hermeneutical deficiencies and the upholding of questionable paradigms in the research field. Interviews with researchers involved in these brain studies reveal targeted and diffuse forms of testimonial injustice against alternative approaches, promoted by the hierarchical arrangements of research teams in combination with the careerist and economic logic of research. The analysis points to the exclusion of critical epistemologies of science and the historical oppression of trans people as epistemic agents as the underlying hermeneutical deficiencies.

Keywords: transgender, neuroscience, epistemology, transdisciplinarity, gender identity, trans studies

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INTRODUCTION

The idea of the existence of neurological traits specific to trans people, is a culturally powerful narrative that has the potential to impact social perceptions, as well as legislative and medical regulations of trans people. Crucially, scholars from Trans and Gender Studies have elaborated a critique of the biomedical construction of trans identities and highlighted the historical and contextual heterogeneity of trans embodiments, focusing on how stigmatizing ideologies and various forms of inequality materialize into living conditions and experiences detrimental to trans people's lives (Valentine, 2007; Spade, 2010; Snorton, 2017; De Silva, 2018; Fütty, 2019). Given the relevance of these insights to any research on or with trans people, a transformative dialogue between the neuroscientists researching the brains of trans people and the knowledge being produced within Gender and Trans studies is a necessary transdisciplinary project.

In a critical analysis from a Gender Studies perspective of a study comparing the structural connectivity networks of trans and cis participants (Caselles, 2018) it became apparent that certain lines of transdisciplinary engagement were already in place. Three fundamental contributions from these engagements could build the basis for a dialogue between Gender Studies and Neuroscience on trans research[1].

The first contribution is the challenging of the "hardwiring" paradigm still dominating neuroscientific research on sex differences. It upholds that the effect of prenatal hormones on the brain of the fetus determines its future gendered behavior, sexual orientation and gender identity.

[1]The listed transdisciplinary contributions are not exhaustive, they can be expanded with further critical works from situated Neuroscience and psychological studies, which were not taken into account in my research.

In her thorough analysis of the "hardwiring paradigm," Rebecca Jordan-Young problematizes the systematic neglect "of the well-established evidence that the brain and the neuroendocrine system (not to mention the rest of the body) are not stable foundations from which behavior and cognition emerge, but develop and change in a constant dialectic with social and material "inputs," including the individual's own behavior, learning, and mood states" (Jordan-Young, 2010, p. 237). A first programmatic attempt at developing a biosocial theoretical framework of the emergence of sex-related differences has been undertaken by Fausto-Sterling et al. (2011a,b). Wood and Eagly (2009, 2012) have also proposed a biosocial concept of gender identity and gender role socialization. Central to this biosocial and developmental approach is the acknowledgment of brain plasticity, meaning that "the brain changes both structurally and functionally in response to the environment and experience" and that "an intrinsic feature of the brain is its sociocultural context dependence" (Han et al., 2013, p. 338, see also Kolb and Gibb, 2014).

The second contribution is the concept of brain mosaicism which challenges the notion of brain sexual dimorphism. The dimorphism model stems from the 3G-model of sex, which groups the variance of genetic, gonadal and genital expressions in a male and a female group[2]. Daphna Joel and her team argue that thinking of the brain as dimorphic, that is, as existing in a male or female variation, is a misrepresentation. In a review of more than 1,400 human brains, Joel and her team found that sex/gender differences in the human brain are neither highly dimorphic, nor internally consistent, "even when considering only the small group of brain features that show the largest sex/gender differences, each brain is a unique mosaic of features" (Joel et al., 2015, p. 15472). The same team have also empirically questioned the idea that core gender identity is clearly binary in cis population (Joel et al., 2014). They developed a Multi-Gender Identity Questionnaire, administered it to cis and trans participants and found "that the current view of gender identity as binary and unitary does not reflect the gender experience of many "normative" individuals" (Joel et al., 2014, p. 315).

Finally, the third contribution stems from the changes in the diagnostic categories and criteria for trans people. In the DSM-5 [APA (American Psychiatric Association), 2013], the diagnosis changed from "gender identity disorder" to "gender dysphoria." The aim of the change was to depathologize gender identity and to focus instead on the suffering or discomfort of trans and gender diverse people. The terminology used in the DSM-5 describes gender identity and gender roles as spectrums and avoids binary and dichotomous logic, thereby acknowledging the existence of gender identity variance. Furthermore, the term "gender" has been used instead of "sex." Sexual orientation, which was a specifier in the DSM-IV, has also been removed (Cohen-Kettenis and Pfäfflin, 2010; Beek et al., 2016). But what makes the DSM-5 so radically different from the previous editions is the shift in its understanding of medical authority. The DSM-5 experts discussed the diagnostic criteria explicitly in relation to the stigmatization of trans people, as well as in relation to access to healthcare. They challenge that the notion that science can define what is regarded as normal or pathological: "There are no scientifically based criteria to differentiate normal and pathological gender identity, and the manner in which any gender identity develops remains unknown and a matter of theoretical speculation" (Drescher et al., 2012, p. 573).

In the aforementioned analysis of a study of the connectivity networks of cis and trans participants (Caselles, 2018) it became clear that these contributions were not being discussed - despite their direct relevance. Instead, the neuroscientists remained committed to the hardwiring paradigm, binary models of sex/gender and pathologizing understandings of trans identity. Was this exclusion specific to this paper or did it affect the whole field? Did the exclusion result from ignorance or was it intentional?

Normative theories of epistemic injustice provide a framework to think about these questions. Its central idea is that discrimination of people as epistemic agents leads not only to the disadvantage of members of groups discriminated against, but to an impoverishment of knowledge overall: "knowledge that is passed on to a hearer is not received. This is an epistemic disadvantage to the individual hearer, and a moment of dysfunction in the overall epistemic practice or system." (Fricker, 2007, p. 43).

José Medina and Miranda Fricker, two of the main theorists of epistemic injustice, distinguish between testimonial injustice and hermeneutical injustice. The core of testimonial injustice is a prejudicial dysfunction in the attribution of credibility by a hearer. Credibility excess and credibility deficit are forms of testimonial injustice, which are systematically linked to each other. Both Medina and Fricker qualify as unjust those forms of credibility excess or deficit that are systematic, that is, "that track the subject through different dimension of social activity - economic, educational, professional, sexual, legal, political, religious, and so on" (Fricker, 2007, p. 27). Other forms of testimonial injustice are pre-emptive testimonial injustice, in which a group is excluded from participating in epistemic exchange, and epistemic objectification, that is, the denial of epistemic subjectivity to certain groups by confining them to passivity and excluding them from epistemic co-operative exchange.

The basis for hermeneutical injustice is the fact that individuals' knowledge of the social world and of themselves is interpretative, meaning that we are all dependent on a pool of hermeneutical resources to make sense of our social experiences. Injustice occurs when collectively available resources to understand oneself and one's social experiences are unevenly informed by the experiences of some social groups to the exclusion of others. Hermeneutical injustice is "the injustice of having some significant area of one's social experience obscured from collective understanding owing to a structural identity prejudice in the collective hermeneutical resource" (Fricker, 2007, p. 155).

My aim is to apply the theoretical framework of epistemic injustice theories to empirically analyze an actual epistemic situation between neuroscientific studies of (trans)gender

[2]"female" = XX, ovaries, uterus, fallopian tubes, vagina, labia minora and majora, clitoris, and "male" = XY, testes, prostate, seminal vesicles, scrotum, penis.

identity and alternative approaches. In order to do this, I combine epistemic injustice theories with an ethnomethodological approach to the study of scientific practices, which reveals the centrality of testimonial and hermeneutical dimensions of scientific facts. Latour has argued that it is not the inherent properties of statements that make them true, but the incorporation of these statements into new ones by other actors. In this sense, facts are collective accomplishments with an essential communicative dimension: "You may have written a paper that settles a fierce controversy once and for all, but if readers ignore it cannot be turned into a fact." (Latour, 1987, p. 40).

Hermeneutical practices in the production of scientific knowledge occur at two levels. The first one is based on the interpretation of observations. At this level, the systematic privileging of certain interpretations can constitute a form of hermeneutic marginalization. The second level is connected to the understanding and meaning of science itself. Differences are found for example between monist and pluralist understandings of science (Kellert et al., 2006, p. xi).

Using theories of epistemic injustice involves a commitment toward a more just production of knowledge. It is in this sense a necessarily interventionist project. Based on a vision of dissent as a democratic epistemic practice, Medina advocates for epistemic friction, which he defines as "contending with," rather than "contending against" (Medina, 2013, p. 16). In this account of epistemic cooperation, he defends the principles of acknowledgment, engagement, and epistemic equilibrium. The first of which means that "all forces that we encounter must be acknowledged and, insofar as it becomes possible, they must be in some way engaged," the second one is the imperative to search "for equilibrium in the interplay of cognitive forces, without some forces overpowering others, without some cognitive influences becoming unchecked and unbalanced" (Medina, 2013, p. 50). He places a special hermeneutical responsibility on institutions and people in positions of power, but stresses that "we all share the collective responsibility to facilitate the hermeneutical agency of all communicators, especially if they have been marginalized" (Medina, 2013, p. 110).

This political and ethical commitment also is found within feminist philosophy of science. Donna Haraway's concept of situated knowledges captures this sense of the individual and collective responsibility of researchers within an understanding of science as historically contingent, constituted through language and meaning, as well as committed to "faithful accounts of a "real" world" (Haraway, 1988, p. 579). Upholding the value of embodied objectivity against traditional epistemology and social constructivist relativism, Haraway argues for "partial, locatable, critical knowledges sustaining the possibility of webs of connection called solidarity in politics and shared conversations in epistemology" (Haraway, 1988, p. 584). The possibility of objectivity and rational knowledge lies then in the "process of ongoing critical interpretation among "fields" of interpreters and decoders," in knowledges "ruled by partial sight and limited voice (...) for the sake of the connections and unexpected openings (...)" (Haraway, 1988, p. 587). I see this account as in harmony with Medina's normative account of epistemic cooperation that provides the theoretical and normative basis for my research.

Building on these frameworks I formulate my research question as follows:

> Which forms of epistemic injustice can be identified in the conceptualization of gender identity in the brain studies of (trans)gender identity?[3]

Within the context of this research question, I align with an approach that can be defined as biosocial, developmental, mosaicist, contextualist, and depathologizing. My understanding of "conceptualization" includes both the formal definitions presented in the published studies and the process by which these definitions were established.

In order to empirically assess epistemic injustice, a transparent operationalization is needed. The criteria formulated below are tailored to the context of scientific research and target the moments of decision-making among alternative options within the research process, including the formulation of research questions, design of experiments or the interpretation of findings. The criteria are not meant to lead to conclusive "yes/no" answers on the question of whether epistemic injustice is to be found in a particular case. Instead, they are meant to provide an evaluative framework to interpret the data gathered.

First, the question of epistemic injustice can only be adequately raised if a number of preconditions are met in an epistemic situation:

> A1. Multiple epistemic agents (individual, collective, institutional) participate actively in the production of knowledge[4].
> A2. There is a shared question or inquiry involving all epistemic agents.
> A3. The knowledge produced by the epistemic agents follows a shared set of values and rules, and is of relevance to the inquiry.
> A4. There must be a power differential in the epistemic situation that corresponds to relations of oppression active in society.

The epistemic situation of this study involves on the one hand the scholars advancing biosocial, developmental, mosaicist, contextualized and depathologizing approaches to brain research and sex/gender and trans identities. On the other hand, it involves

[3]In order to establish a dialogue between different disciplines and approaches, I chose a pragmatic approach to the use of terminology. The terms "transgender"/"trans" and "cisgender"/"cis" are extracted from the field, following the vocabulary of recent neuroscientific papers (see Burke et al., 2017; Nota et al., 2017; Manzouri and Savic, 2018 for example) that seemed the most compatible with terms as used in gender and trans studies. The same applies to the use of "gender identity", taken from the field. The downside is that through this pragmatic approach, limitations, and problems bound to these terms are reproduced.

[4]I am limiting the epistemic agents in my analysis to those who actively participate in the production of knowledge within the delimited epistemic situation because of my focus on the question of responsibility and accountability for unjust epistemic practices. This excludes the cis and trans participants from my consideration.

brain studies of gender identity (BSGI). The term "brain studies of gender identity" is used in this paper in a narrow sense. It refers to neuroimaging studies that state "gender identity" as their main object of research, operate by comparing the brain structure and function of trans and cis participants, and aim toward a neurological theory of gender identity formation. Consistent with my praxeological approach, the use of the term is descriptive and captures how the studies present themselves. It is important to note that this use of terminology reproduces a problematic and undifferentiated notion of gender identity as a one-dimensional self-contained category, a conceptual issue that is investigated and discussed in sections Conceptualization of Gender Identity in Published Brain Studies of (Trans)Gender Identity, Epistemic Attitudes From Researchers of Brain Studies of (Trans)Gender Identity, and On Epistemic Injustice in Brain Studies of (Trans)Gender Identity of this paper. The BSGI do not include neuroimaging studies with trans participants looking into the effects of hormone replacement therapy on brain structure or function (see for example Burke et al., 2018), nor studies with trans participants with research objects that are not explicitly gender identity, such as ostracism (for example Mueller et al., 2018) or reaction to stimulation of body parts (see for example Case et al., 2017).

These two sets of epistemic agents configure an epistemic situation in which they are all directly involved in seeking to understand gender identity and are accountable to scientific standards for empirical research, even if they deploy different methodologies. As a baseline, all of the epistemic agents hold positions in universities or research institutions and have published their work in peer review journals to which the other researchers have access.

The power differential between these epistemic agents (A4) is, however, more difficult to argue. This is because I have narrowed down the epistemic injustice situation as occurring within the realm of science, that is, between epistemic agents that qualify as scientists, which is a position of social privilege. The difference between the epistemic agents that I am considering is not one of gender identity, sexual orientation, race, class or other category of social inequality. There is however a key difference in that some epistemic agents operate within dominant and hegemonic discourses, while biosocial, developmental, mosaicist, contextualist, and depathologizing views represent counter-hegemonic positions. The counter-hegemonic stance is directed against two central dispositives of western modernity: the sex/gender binary norm, and the scientific authority over what constitutes nature. Historically, these two strands have come together in the normative legal and biomedical definitions of manhood and womanhood as the only two possibilities of social and political existence in western nation-states.

Thus, the four preconditions that enable one to analyze whether an epistemic situation is shaped by epistemic unjust behavior are met. The focus of my inquiry are therefore the following four conditions, which establish the framework to assess epistemic injustice and guide my research design:

B1. The wrong of the dominant epistemic agent must amount to blocking the epistemic labor of others, devaluating the epistemic labor of others, and/or appropriating the epistemic labor of others.

B2. There must be a form of exclusion or limitation in the participation in the production of knowledge that keeps epistemic agents isolated from one another and/or there must be a breach in the relationship of trust between the epistemic agents involved.

B3. The harming of the oppressed epistemic agent must benefit the dominant epistemic agent in the perpetuation of the privileges granted through the relations of dominance and oppression which structure society.

B4. The harm produced by the dominant epistemic agent must amount to a failing within the rules of the epistemic system, to a failure of the epistemic system or to the inadequacy of the system altogether.

In order to make the criteria less exigent, I narrow them to alternatives that operate within the same epistemic system, in this case, empirical scientific research in general and biology and neuroscience in particular. This is to be seen as a strategic restriction, since I would defend that epistemic agents have a responsibility to pay attention and engage with knowledge from epistemic systems other than their own.

MATERIALS AND METHODS

Content Analysis

The first part of the study is a qualitative content analysis (Mayring, 2015; Krippendorff, 2018) of BSGI to analyze how gender identity is defined in published studies. The qualitative content analysis can establish whether the definitions of gender identity meet quality criteria of conceptual work such as clarity, specificity, coherence, or consistency. This analysis can also show whether the conceptualization engages with biosocial, developmental, mosaicist, contextualist, and depathologizing approaches. Therefore, the qualitative content analysis is an adequate method to evaluate the conditions B1 (blocking, devaluing, or appropriating the epistemic labor of others), B2 (exclusion or limitation in the participation in the production of knowledge), and B4 (failing within the values of the epistemic system).

The content analysis was divided into two steps: first, a detailed analysis of four early studies (2011–2014), and second, a targeted analysis of six recent studies (2016–2018). The sample for the first analysis was based on the relevance of the findings for the BSGI field: Savic and Arver (2011), Rametti et al. (2011a,b), and Kranz et al. (2014). The sample of the recent studies was based on publication date, inclusion of different approaches, relevance of the findings, and availability of researchers for the interview: Guillamón et al. (2016), Burke et al. (2017), Feusner et al. (2017), Manzouri et al. (2017), Nota et al. (2017), and Manzouri and Savic (2018).

The procedure for the analysis was developed with a pre-test of a previous study (Berglund et al., 2008). In the analysis I considered the terms "gender identity," "sex," "gender," "transgender" (and related terms such as "gender dysphoria," "gender identity disorder," "transsexualism"), "women/female,"

"men/masculine" and terms related to "sexual orientation." I accounted for explicit definitions and the use of the terms[5].

In the analysis of the early studies, I conducted a quantitative assessment of the frequency of use of the terms[6]. For the qualitative analysis of the most frequently used terms, I took into account explicit definition and uses of the terms. I differentiated the uses within theoretical expositions, operationalizations or interpretations of findings. I also analyzed the use of different terms in relation to each other. Then, I analyzed expressions of sexual differentiation of the brain, that is, expressions that communicate the measurements obtained in a study (own or other) and interpret them in relation to O/A hypotheses. Finally, I included in the analysis explicit definition of the considered terms from cited theoretical papers. The findings of the analysis of the early studies are presented in section Conceptualization of Gender Identity in the Recent Brain Studies of (Trans)Gender Identity (2011–2014).

The analysis of the recent studies was a comparative analysis, focused on changes in relation to the earlier studies. In order to do this, I accounted for theoretical shifts in the field. The conceptualizations of gender identity were then analyzed separately for the two hypotheses proposed in the recent studies. I analyzed explicit definitions and uses of "gender identity" and the aforementioned terms in the theoretical expositions, operationalization, and interpretation of findings. The findings of the analysis of the recent studies are presented in section Conceptualization of Gender Identity in the Recent Brain Studies of (Trans)Gender Identity (2016–2018), while a joint discussion of the findings in the early and recent brain studies follows in section Summary of findings of the conceptualization of gender identity in published brain studies of (trans)gender identity.

Expert Interviews

The second part of the study is an assessment of the researchers' epistemic attitudes toward the alternative approaches. I used qualitative expert interviews for this purpose (Kaiser, 2014). The interviews combine exploratory questions to generate new insights in the conceptualization process, with structured questions to evaluate the following necessary conditions for epistemic injustice: B1 (blocking, devaluing or appropriating the epistemic labor of others), B2 (exclusion or limitation in the participation in the production of knowledge), B3 (perpetuation of privilege granted through relations of dominance and oppression), and B4 (failing within the values of the epistemic system, failure or inadequacy of the epistemic system altogether).

The interview script was designed to introduce epistemic friction by asking about conceptual problems of the BSGI, as well as about biosocial, developmental, mosaicist, contextualist, and depathologizing approaches. The challenge was to avoid an oppositional framing and instead promote a dialogue between dissenting stances.

I approached this by establishing a common ground between myself as the interviewer, the BSGI researchers, and alternative conceptualizations. This common ground was based on four openings in the recent studies: (1) the dismissal of the inverted brains hypothesis in favor of a reconceptualization of trans brains as a composite of masculinized and feminized traits, potentially opening the research toward a mosaicist model of brain sex differentiation, (2) emphasis on development which enables the discussion of brain plasticity and environmental factors, potentially moving away from biological determinist models of gender identity, (3) the introduction the diagnosis of "gender dysphoria" in the DSM-5 which acknowledges non-binary gender identities, potentially opening the field toward multidimensional and socially contextualized understanding of gender identity for trans people, and toward a denaturalization of diagnostic categories, and (4) consideration of social experience as a factor shaping brain networks, potentially opening research toward multidimensional, intersectional and socially contextualized understandings of gender identity for both trans and cis people.

I developed questions that create a space for discussion: "How relevant do you consider theory x for the neuroscientific study of gender identity?," "What benefits and problems do you see in approach x at a theoretical and methodological level?," "Was this conceptualization x topic of discussion?." For questions with an either-or logic, I attempted to establish in the formulation a collaborative focus, for example: "Do you think that x should inform neuroscientific research on gender identity?[7]."

I sent interview requests to 11 researchers and received 4 positive responses, 4 declines, and 3 unanswered. I conducted four interviews that lasted between 37 and 70 min and recorded the audio. I adapted the interview script to each researcher focusing on the area of expertise. I transcribed the interviews following a simple transcription method (Dressing and Pehl, 2015). A first transcription was sent to the interviewees for revision. In order to create a relationship of trust, but also to reflect potential changes in the epistemic attitude of the interviewees, I allowed them to introduce modifications to the transcription. One researcher decided to retract the interview after reading the transcript, which is why the analysis is limited to three interviews. Researcher B introduced modifications in the transcript, which became much shorter and closer to a written text and left out many questions and answers. The interview transcripts were then anonymized.

The interviews were analyzed following a simple qualitative content analysis focusing on two categories. The first, communicative context, reflects the interviewees' construction of the social field[8] in which they situate their own work and that provides the background for their conceptual decision-making. This category enables a description of the epistemic attitude in relation to the constraints that dominate the social

[5]The **Supplementary Materials** include an extended report on the selection procedure and a full list of the analyzed terms.

[6]I excluded Rametti et al. (2011b) from the quantitative assessment because of the parallels in use of the terms to Rametti et al. (2011a).

[7]See full interview script in the **Supplementary Material**.

[8]The concept of social field follows Bourdieu's definition of social field as "a field of forces, whose necessity is imposed on agents who are engaged in it, and as a field of struggles within which agents confront each other, with differentiated means and ends according to their position in the structure of the field of forces, thus contributing to conserving or transforming its structure" (Bourdieu, 1998, p. 32).

field. The findings of this analysis are presented in section Communicative Contexts. The second category is epistemic behavior, specifically in relation to the conceptual problems and alternative approaches. This category is a praxeological one, framing the reaction in terms of "doing": what does the researcher do with the conflict? How does the researcher handle it? This takes into account both the content level and the performative level of communication, paying attention to the arguments offered and how they function within a range from refusal or blocking to engagement and agreement. The results of this analysis are presented in section Epistemic Behavior.

CONCEPTUALIZATION OF GENDER IDENTITY IN PUBLISHED BRAIN STUDIES OF (TRANS)GENDER IDENTITY

Conceptualization of Gender Identity in the Recent Brain Studies of (Trans)Gender Identity (2011–2014)

Frequency of Use of Sex/Gender Related Terms

The use of sex/gender related terms differs in absolute numbers between the three studies, but shows a consistent pattern (see **Table 1**). The terms most used are "men/male" and "women/female," followed by terms related to "trans" and "sex." The numbers show a consistently low frequency of use of "gender" related terms, despite it being the main object of the studies' research.

Explicit Definitions of Gender Identity

None of the four studies included an explicit definition of "gender identity." The most elaborate were formulations such as "perceptions of the own sex" (Savic and Arver, 2011) or "the male controls have a gender identity as men (…) and control women have a gender identity as women" (Rametti et al., 2011b). This is remarkably poor considering the centrality of gender identity in the research question.

The theoretical papers cited in the studies contained two brief definitions, both within a parenthesis. In the first one, gender identity is distinguished from "sex," defined as a form of belonging, and limited to a masculine or feminine identity as mutually exclusive and homogeneous categories: "Gender identity (gender identity refers to an identity experience expressed in terms of masculine or feminine "belongingness," independent of the anatomical reality of the sex) (...)" (Swaab, 2004, p. 303). In the second one, this "feeling of belonging" is related to gender, without explaining the term any further and remaining within the male-female dichotomy: "… gender identity (the conviction that one belongs to the male or female gender)..." (Bao and Swaab, 2011, p. 215). Both definitions are embedded in explanations of transsexuality, establishing a normative dimension by which the main aspect of gender identity is the distinction between ordered (cis) or disordered (trans). This subordinates the concept of gender identity to the definition of transsexuality and centers cis identities as an invisible norm.

Etiological Definition of Gender Identity

The theoretical framework of the four studies is the brain organization/activation (O/A) hypothesis, particularly the discussion thereof by Swaab (2004, 2007), Garcia-Falgueras and Swaab (2008), and Bao and Swaab (2011). The O/A hypothesis proposes that a permanent structuring ("hardwiring") of the brain into a male or a female variation occurs based on the influence of gonadal testosterone on the developing brain of the fetus and immediately after birth. These "hardwired" brain patters are proposed to cause differences between men and women in gender and gender identity, including behavior, personality traits and feeling of belonging (see Bao and Swaab, 2011, p. 215).

Gender identity is introduced in the hypothesis to explain transsexuality through the separate timing of genital and brain differentiation during pregnancy. The separate timing opens up the possibility of changes in the hormonal environment in which brain and genital differentiation happen:

> "These fetal and neonatal peaks of testosterone, together with functional changes in steroid receptors, are thought to program to a major degree the development of structures and circuits in a boy's brain for the rest of his life. As sexual differentiation of the genitals takes places much earlier in development (i.e., in the first 2 months of pregnancy) than sexual differentiation of the brain (the second half of pregnancy), these two processes may be influenced independently. In rare cases, this may result in transsexuality, i.e., people with male sex organs who nevertheless have a female identity, or vice versa. It also means that in the event of an ambiguous sex organ at birth, the degree of masculinization of the genitals may not always reflect the degree of masculinization of the brain" (Bao and Swaab, 2011, p. 215).

The implication of this etiological hypothesis is that chromosomal and genital sex need to be seen in all people as independent from gender identity and, by extension, that neither chromosomal xx/xy variation, nor the presence of a penis or a vagina, can be used as reliable indicators of the hormonal environment during the fetal brain development. This implication is ignored by the authors in BSGI and the proponents of the O/A hypothesis, but it has far reaching consequences for the whole field of studies of sex/gender differences in the brain. Studies that use chromosomal, genital or gonadal sex as indicators of the hormonal environment during fetal brain development or as an indicator for the gender or gender identity of the participants can't be seen as reliable. Based on the O/A hypothesis itself, this combination of inferences is not valid, meaning that gender and gender identity need to be assessed in all people independently from 3G-sex and that 3G-sex can't be used as a reliable indicator of hormonal environment during brain development. The undetected logical inconsistency in the application of the hypothesis in BSGI shows the detrimental impact of unreflected cultural and normative assumptions of sex/gender on the research field.

Operational Definitions of Gender Identity

In all four studies, participants were selected based on sex and gender identity. None of the studies mentions how the gender

TABLE 1 | Absolute and relative frequency of use of sex/gender related terms in selected studies.

	Savic and Arver (2011)		Rametti et al. (2011a)		Kranz et al. (2014)		Total	
"sex"	50	25,6%	44	19,4%	54	18,1%	148	20,55%
"gender"	2	1%	18	7,9%	27	9%	47	6,5%
"men/male," "women/female"	59	30,3%	82	36,1%	110	36,9%	251	34,9%
"sexuality"	40	20,5%	12	5,3%	24	8,1%	76	10,55%
"trans"	44	22,6%	71	31,3%	83	27,9%	198	27,5%
	195	100%	227	100%	298	100%	720	100%

identity of the cis participants was established. At the same time, trans participants underwent an exhaustive control of their gender identity based on diagnostic procedures and criteria of the DSM-IV and ICD-10. The fact that only the gender identity of trans participants was operationalized shows the extent to which the conceptualization of gender identity is dependent of the ordered/disordered dimension of a medical diagnosis and how a cis bias stands in the way of a thorough interrogation of the category of gender identity.

The use of a medical category for the assessment of gender identity in combination with the etiological model proposed by the O/A hypothesis by which gender identity is hardwired through the effect of prenatal hormones on the brain leads to a fundamental hermeneutical problem in the BSGI. The biologization of transsexuality erases the historical and political dimension not only of sex and gender, but also of medical categories and techniques.

On the Use of "Brain Sex," "Biological Sex"

In the studies, the term sex is used in expressions such as "biological sex" and "brain sex." In "biological sex" it refers to a series of elements such as genital phenotype, reproductive organs, gonads, production of androgens and estrogens, and chromosomes. These factors are linked by a chain of events and processes. Within the O/A hypothesis, the development of the brain is determined by "sex" in the sense that it is assumed to be shaped permanently by the gonadal hormones. It is in this sense that "brain sex" can be understood as expressing the causal subordination of brain structure and function, as well as their outcomes (behavior, attitudes, cognition, emotion, identity, etc.), to factors of biological sex (see Savic et al., 2010, p. 15).

The term "brain sex" is misleading in a crucial way. Taking the O/A hypothesis seriously, that genitals and brain differentiation occur at different times during pregnancy, "sex" in "brain sex" stands for the hormonal environment during the brain development phase of the fetus in which the "gender" gets hardwired. However, as the hypothesis proposes in the explanation of transsexuality, this hormonal environment can't be assumed from chromosomal, genital or gonadal sex, and the outcome as male/female gender identity can't be predicted by either gonadal sex or chromosomal sex or genital sex. Thus, the use of "brain sex" creates a false correspondence between chromosomal sex, gonadal sex, genitals, brain structure, gender, and gender identity in a male expression or a female expression.

Definition of Transgender Identities and Sexual Orientation

The most elaborate definition in the studies refers to terms related to transgender identities. The authors of all studies include a diagnostic definition based on the criteria of DSM-IV and ICD-10:

> "(1) A desire to live and be accepted as a member of the opposite sex, usually accompanied by a sense of discomfort with the subject's anatomical sex and a wish to have surgery and hormonal treatment to make the body as congruent as possible with the body of the preferred sex.
> (2) The transsexual identity has existed for at least 2 years.
> (3) The syndrome cannot be explained by any other psychiatric disorder or by chromosomal abnormality. Thus, any evidence of an abnormal male phenotype or genotype (i.e., hypospadias, cryptorchism, micropenis, and chromosome complement other than 46XY) excluded enrollment to the study" (Savic and Arver, 2011, p. 2,526).

Based on the O/A hypothesis, transgender identity is also understood as "a mismatch between gender-specific brain development and the development of body and genitals" (Kranz et al., 2014). They combine these two definitions with the typological differentiation of trans people in a "homosexual" and "non-homosexual" category based on Blanchard's discredited hypothesis. The typological definition is used by the researchers to control for sexual orientation as a factor.

"All FtM transsexuals selected had early-onset gender non-conformity (before puberty), were erotically attracted to females, and wanted sex reassignment (Gómez-Gil et al., 2009). This group corresponds to the one typically referred to as "homosexual type" (Blanchard et al., 1987; Smith et al., 2005; but see Gooren, 2006). Sexual orientation in patients was established by asking what partner (a man, a woman, both or neither) the patient would prefer or feel attraction to if they were completely free to choose and the body did not interfere" (Rametti et al., 2011b, p. 950).

The reason for the assessment of sexual orientation is that the O/A hypothesis also applies to the "hardwiring" of a sexual orientation. Therefore, the variable sexual orientation is assessed to either limit the selection of participants to "heterosexuality" or to use it as covariate. Following Gooren (2006), Moser (2010) and Veale et al. (2012) critique of the Blanchard typology, the operationalization of sexual orientation for the cis and trans participants is contradictory. For example, trans men attracted

to women are defined as homosexual (Rametti et al., 2011a, p. 200). The Kranz et al. study is the only one that accounts for different possibilities to operationalize sexual orientation based on a scale of attraction toward males and females, on a spectrum of homosexuality and heterosexuality based on genetic sex and on the same spectrum based on gender identity (see Kranz et al., 2014, p. 15469).

The studies' use of multiple definitions of transgender identities without acknowledging incompatibilities and the contradictory assessment of sexual orientation contribute to the lack of conceptual clarity and accountability.

Conceptualization of Gender Identity in the Recent Brain Studies of (Trans)Gender Identity (2016–2018)

In order to assess the recent BSGI it is necessary to account for theoretical shifts in the field. The changes were necessary because the findings didn't show a "brain sex reversal" in trans participants, but a mix of traits: "the MtF brain is not completely feminized but presents a mixture of masculine, feminine, and demasculinized traits" (Guillamón et al., 2016, p. 1627). The first hypothesis used to explain these findings is the cortical development hypothesis (CD), which adapts the O/A theory to match the findings. The second hypothesis is the self-referential thinking and body perception hypothesis (SR/BP), which operates within neurological theories of the self. Another development that affected recent studies was the release of the DSM-5, which introduced relevant changes in nomenclature from "gender identity disorder" to "gender dysphoria," and demonstrated a deeper understanding of transgender identities.

Cortical Development Hypothesis

This hypothesis is presented in a review paper and has not been empirically tested. It proposes "a slowing (or a stop) in the cortical thinning process in females, MtFs, and FtMs compared to the thinning process in males," which would create different cortical phenotypes: "this hypothetical process, based on differential developmental processes in specific cortical regions, would influence the development of gender identity for all: male, female, MtF, and FtM" (Guillamón et al., 2016, p. 1637).

In relation to the conceptualization of gender identity, the CD hypothesis does not provide any further elaboration on the O/A model. The shift is that gender identity is defined not through a male and female pattern that is reversed in the trans brain, but through a "thinner than male" cortical thickness pattern. While the first pattern was proposed based on a binary oppositional concept of sex and gender, this new pattern has no logical correspondence to the conceptual definition of sex/gender, which is maintained as binary and oppositional.

The CD hypothesis does not integrate the changes in conceptualization of the DSM-5, despite citing it as a reference. Instead, the CD hypothesis makes extensive use of Blanchard's typology of transsexuality and "feminine essence theory" (Blanchard, 2005, 2008), disregarding it's sexist and homophobic logic and its incompatibility with the understanding of gender incongruence of the DSM-5.

Self-Referential Thinking and Body Perception Hypothesis

This alternative hypothesis seeks to describe the networks involved in accomplishing tasks such as recognizing one's own body as one's own. It includes a definition of gender identity that considers a series of factors: "gender identity denotes a complex interrelationship among an individual's genital sex, one's internal sense of self, and one's outward presentations and behaviors (gender expression)" (Manzouri and Savic, 2018, p. 1). However, there is no acknowledgment that the internal sense of self and one's outward presentations and behaviors are related to sex/gender, due to the fact that neurological theories of the self don't have a concept of gender (see Northoff et al., 2006, p. 454). Gender dysphoria is thus redefined as "body dysphoria and body-related avoidance" (Feusner et al., 2017, p. 965), erasing gender as a dimension.

The conceptualization of gender dysphoria away from sex/gender models introduces a shift in the question of causation. The authors move away from a "neurobiological determinant" to a "neurobiological substrate," taking into account plasticity and development in what can be understood as a shift toward a biosocial reconceptualization (see Manzouri et al., 2017, p. 1008). Some studies introduce a developmental understanding of gender dysphoria, focusing on aging and brain maturation and activational effects of hormones in puberty, and disregarding the effects of differing social experiences (see Nota et al., 2017).

In the SR/BP hypothesis sexual orientation figures as a separate phenomenon, leading to the interpretation that "the neuroanatomical signature of transgenderism is related to brain areas processing the perception of self and body ownership, whereas homosexuality seems to be associated with less cerebral sexual differentiation" (Burke et al., 2017, p. 1). The conceptual entanglement of gender identity and sexual orientation is not considered.

Summary of Findings of the Conceptualization of Gender Identity in Published Brain Studies of (Trans)Gender Identity

Overall, the definitions and use of the terms "gender identity," "sex," and "gender" fail to meet sufficient levels of accuracy and differentiation. In addition to the studies' general lack of clarity, I see three severe conceptual problems.

The first conceptual problem lies in their disregard of the theoretical and methodological implications of the postulated temporal separation of 3G-sex and gender identity. This problem can be understood as a form of internal conceptual inconsistency. In relation to the conditions defined in the operationalization of epistemic injustice, this conceptual inconsistency represents a problem within the rules of the experimental method.

The second problem is the hermeneutical misconception by which cultural norms, practices and techniques of gender are naturalized and turned into biological entities. This is evident in the usage of transsexuality as the only explicit frame of reference for gender identity, as well as in the failure to operationalize gender identity for cis participants. The

hermeneutical misconception points to a possible inadequacy of the theoretical and experimental approach of the BSGI to acknowledge the socio-cultural dimension of its research object and stands in the way of a complex understanding of gender identity for all people.

The third problem is the upholding of questionable paradigms, such as biological reductionism and determinism, as well as the binary model of thinking about sex/gender and brain. These frameworks contradict knowledge of the biosocial and dynamic quality of brain development and the evidence of sex/gender diversity presented in the introduction. While there is an emphasis on the developmental logic in both SR/BP and the CD hypotheses, and the SR/BP is open to the acknowledgment of brain plasticity, no social or cultural variables affecting gender identity or brain development were considered relevant. While it is important to acknowledge the opening and to take its potential for future research seriously, both hypotheses remain attached to reductionist thinking. This third conceptual problem represents a failure to acknowledge relevant bodies of work, and thus a failure of the epistemic system to detect and prevent harmful ignorance.

EPISTEMIC ATTITUDES FROM RESEARCHERS OF BRAIN STUDIES OF (TRANS)GENDER IDENTITY

Communicative Contexts

The interviewed researchers of the BSGI belong to different research teams and have different tasks, experience levels and academic status. This leads to contrasting perceptions of the work in the research teams, the broader scientific community and the socio-political context of the studies.

Researcher A

Researcher A works as a doctor in a gender clinic and is thus accountable to diagnostic manuals such as the ICD and DSM, national laws on name and sex change registration and healthcare system regulatory bodies. Researcher A also works closely with trans patients and trans organizations and is aware of the conflict between the regulatory framework of the gender clinic and the healthcare needs of trans people who go there. Researcher A is recruited to work on the BSGI and entered the research team in a subordinated relationship with the principal investigator, who is the funding receiver and ultimate decision-maker. The question of access to funding highlights the entanglements between career logic and the logic of knowledge production. However, researcher A points to the crucial difference of having a regular salary as a doctor and the situation of researchers, who have to "spend half of their work time to apply for money (…) and in that, they need to sell."

Researcher A brings into the team an awareness of the political dimension of scientific research on trans topics: "(...) you have to fight if you do studies with people who are not in trans medicine, they want to use what they think is simple language. So, why complicate it, it's a female-to-male (...) and there's whole other studies using this, we cannot not use it." For researcher A the political dimension of medical and scientific work with trans people makes it necessary for researchers to intervene in public debates to prevent harmful use of findings. This involves a self-positioning in relation to the distributions of privilege and power involved in research: "I am privileged, I have a reputation, I have a salary (…) and I can feel stressed by being in these sometimes hostile surroundings (…). But the trans patient (…) is of course even more in this needle of a hurricane." Researcher A sees a need to involve trans people when planning research to think about "what questions are more urgent to answer, what is interesting, what is important?." This stance of Researcher A includes an awareness that trans people "have different views of things" and that some trans organizations think that there should be "no medical people at all."

Researcher B

Researcher B has been studying sex differences in the brains of mammals for over four decades. Their involvement in BSGI with trans patients was motivated by technological developments in neuroimaging techniques. Researcher B sees the collaboration with other research groups and institutions as a "functional team that is constituted to answer questions about gender identity and involves several universities and hospitals." The gender unit is for researcher B purely instrumental: "the gender unit of the hospital is the one that has *nourished* all the studies that we have carried out" (my emphasis).

As a principal investigator, Researcher B seeks to enter into dialogue with the wider scientific community working on the same or related questions. Central to being able to participate in this dialogue is the use of a shared methodological approach that facilitates the integration of results "I decided, according to previous researchers, to approach the issue of gender identity in a very simple way: contrasting the brains of transgender men and women with non-transgender men and women."

In researcher B's understanding, science and politics should be kept separate, since "research needs serenity and not looking for results that confirm particular ideas about what human nature looks like." Researcher B rejects the use of terms such as "cisgender" because it was "invented by Volkmar Sigusch more than 20 years ago" and because it is not known by "people in the street." This raises the question of what makes the category of "cisgender" more "invented" or politically motivated than categories such as "transsexualism," "gynephilia," or "gender dysphoria." This shows that the boundary between natural/scientific categories and socio-political categories for researcher B is not dependent on the origin of the categories but of how established they are in scientific discourse. At the same time, Researcher B holds the view that "it is important (...) to use a vocabulary that is respectful and recognizes the variety of our species."

Researcher C

Researcher C got involved in the BSGI in order to complete a PhD and was new to the topic at the time. Researcher C worked on BSGI in two different research groups. For researcher C, their participation in the research is structured around their relationship to a supervisor, who owns the research data.

Researcher C also highlights the importance of funding policies and the difficulties to get money as "the transgender topic is not super sexy to funders," mainly because "it's still only a small minority that are affected by it." This economic situation keeps the field of BSGI small and concentrated into a few established teams. The only way for younger or less established researchers who are interested in pursuing innovative hypotheses is to work unpaid "in the evening hours and weekends."

In the entanglement between the career logic and the logic of knowledge production there is a tension between collaboration and exchange on the one hand and protectionism on the other hand. Researcher C recounts instances in which collaboration requests from researchers with alternative approaches were denied because the heads of research were "very suspicious on opening up, allowing others to test their hypotheses on their data." Researcher C participates and advocates for collaborative projects with shared data pools as a way to avoid the concentration of power in the knowledge production in "certain personalities" who decide "why certain hypotheses were tested and others were not."

Epistemic Behavior

Biological Determinism and Biosocial Approaches

In the first conceptual question I asked the interviewees thought how relevant they considered biosocial frameworks for the neuroscientific understanding of gender identity and gender incongruence.

Researcher A's understanding of gender identity was based on Fausto-Sterling's theory of gender identity development, rejecting mechanistic and reductionist models: "the concept of self could not be (…) in one nucleus deciding if we are male or female as a matter if they are big or small. It must be a network giving us this. And I also think that the way we see our body is also in a network - that we, no matter whether we are gender incongruent or not, but how we see our body is formed by connection between your body and your brain and how you interpret that."

Researcher B preferred in this question to their own theory as "a first explanation of all possibilities" and defined gender identity as "the feeling of congruence or incongruence in relation to the sex assigned at birth" and as a "function of the brain." Researcher B's response delimits gender identity to "the interaction between very complex functional brain networks" and remains within a biologically deterministic framework. The implication is that researcher B does not consider biosocial frameworks as very relevant to the field, but rather than acknowledging or actively rejecting this alternative framework, the researcher blocks the dialogical space with their own theory.

Researcher C takes a synthesizing approach in which the SR/BP hypothesis is combined with the O/A hypothesis. This model considers "sex hormones and especially puberty" as "extremely important" for the development of gender identity and the concept of the self, but includes a dimension described as "identity development in general, so "how ok you are yourself with your body? how positive or negative you think about yourself." Not just in terms of body image, but more generally." This latter aspect could be interpreted as a possible opening to biosocial thinking, although it is presented in an additive rather than interactionist or dynamic manner.

Brain Sex Dimorphism and Brain Mosaicism

Here, I interrogated the stance of the interviewees regarding brain mosaicism as a conceptualization of brain differences between men and women, as well as the critiques of the dimorphic model.

Researcher B stated to "know the work that you mean" and moved on to reject it based on its lack of correspondence with their own data: "I don't agree with that kind of approach because it's not what I've seen." However, in the next sentence, researcher B expresses a different stance without acknowledging the contradiction, reframing the brain mosaicist model as a political attitude: "I understand the feminist attitude and agree that dimorphic differences (two different forms) are observed only in the reproductive system and that the rest of the differences can be called sex effects." Despite the affirmation of knowing this line of work, Researcher B misrepresents the brain mosaicist approach, which does not hold that the measured traits in the brain are "sex effects," but dynamic interactions between multiple social and biological factors.

Researcher B goes on to emphasize the importance of the sex differences in relation to "morphology, physiology, behavior," as well as "genetic expression," "prevalence of psychiatric and neurodegenerative diseases," "pharmacokinetics and pharmacodynamics," and "neuroimmunology," finishing with the rhetorical question "How do we explain all this from environmental factors and from a theory of patriarchy? Impossible." Again, the researcher misrepresents the mosaicist model as denying or downplaying existing differences between people of different sexes/genders and frames it as a political theory.

Researcher C does not directly present their own stance on the question but instead reports a situation in which a proponent of the mosaicist model reached out to a supervisor of the researcher whose research is situated within a dimorphic model, in order to collaborate and test the mosaicist hypothesis with the data of the supervisor. Researcher C argues that "it would have been of value to collaborate on that part, I think it is very relevant," acknowledging the value of the brain mosaicist approach.

Intersectionality and Categorization

I asked the interviewees to consider whether intersectional approaches should inform neuroscientific research and what difficulties this would entail. Researcher A engaged openly with the question, thinking about the relevance of the category "race." Researcher A makes the appropriateness of an intersectional approach dependent on the research question and argues that it might be important to include the category "race" in the study of "gender identity" if a researcher wants to account for the fact "that stress or being in a minority position affects your brain." When speculating about the possible ways in which race, gender identity and context of upbringing might interact with each other and affect brain development, Researcher A raises the problem of the feasibility of such a study: "there are too many millions of confounding factors which you cannot really control

for." In the response, Researcher A shows an understanding of intersectionality, engages with its implications and points to the limitations of neuroimaging studies for a complex understanding of gender identity development.

Researcher C, on the other hand, is unfamiliar with the concept but engages with it after asking me to explain it with an example. Researcher C proposes the use of covariants such as race or sexual orientation as a way to introduce an intersectional perspective. This misses the point of intersectionality as covariants follow an additional logic of the different factors and work toward the isolation of one "pure" factor, while the idea of intersectionality is precisely the entanglement of the different dimensions. Thinking about the interactions between the categories of gender identity and sexual orientation, Researcher C recalled unexpected findings where "cis lesbian groups" have values in brain measurements that "are even more male-typical than the trans males" and wonders "what's going on there? Did they use anabolics, for example?." This train of thought reflects the difficulties in moving away from a paradigm of clear categories, as well as the tendency to focus on biological and quantifiable factors. However, beyond disciplinary and methodological barriers, the inaccurate understanding of intersectionality might also reflect my inability to make these points clear in the context of the interview.

Operationalization of Gender Identity in Cisgender Participants

I asked the interviewees to explain how the gender identity of cis participants was assessed in the studies that they were involved in.

Researcher A reported first that they were assumed but then became unsure and pointed to the principal investigator as the person who could answer my question.

Researcher B refused to answer and left the question out of the edited transcript altogether.

Researcher C recalls using a questionnaire with subscales for both cis and trans participants but adds "we never mentioned that, that's true." The researcher explains how for cis participants "who have never had any identity issues, it's the most simple question to ask: are you a boy or a girl? They say 'yeah, of course, I am that'." Since I was interested in the theoretical or conceptual challenge of understanding gender identity for cis and trans people, I pointed to the fact that "it can still mean different things when two cis people say "I am a boy" or "I am a woman." What that means can still vary because they have different ideas of what that means." Researcher C agreed with the importance "from a methodological point of view" to "characterize your sample in a more detailed way," but immediately linked this to controlling "that none of your cisgender people struggles with identity issues." The response shows again that the conceptualization of gender identity in the BSGI is constructed around the distinction of trans/incongruent and cis/congruent, erasing the complexity of the category. The rationale offered is a pragmatic one: "the simple distinction is to include someone with a diagnosis and those who not."

Gender Diversity and Non-binary Identities

The interviewees were asked about the implications of the acknowledgment of non-binary gender identities in the DSM-5 for the field. The question aimed to challenge the assumption of bipolar and dichotomous gender identities that dominated the BSGI.

Researcher A explains the novelty of non-binary identities as a result that "few people told us" in the beginning, "even if they of course existed." Researcher A explains the exclusion of non-binary participants because in "this type of research you need to have, in quotation marks, "clean" group as possible." The acknowledgment of non-binary identities leads researcher A to a profound interrogation of the meaning of gender identity in both trans and cis populations "(...) if you ask 10 cisgender women how can you describe your female gender identity? you get different explanations. That's the main problem with gender identity, that it is so subjective for each individual."

For researcher B, non-binary identities are contained within gender incongruence as a "minority that is not binary, present incongruence with the assigned sex or feel that they belong to another gender, or experience changes over time with respect to gender identity, or feel that they do not belong to any gender." This framing of non-binary identities leave the binary model of two genders and distinction congruent/incongruent as structuring notions largely unchallenged.

Researcher C welcomes changes in terminology as less stigmatizing for trans people but expresses difficulties grasping non-binary identities. Researcher C states to not really "understand what it is to be gender non-binary," unlike binary trans people, who "request testosterone treatment then and surgical changes (…) in order to get my body the way I feel I am." The medicalized trajectory of a binary sex change is a real phenomenon to Researcher C, but not non-binary identities. Researcher C wonders "how real that phenomenon is? Is that really (…) from people who experience actually this feeling and who only now dare to share that, or is it more some kind of trend that allows you to get the autonomy of defining yourself as whatever you like because it is possible?." The influence of cultural context on the articulation and expression of gender identities ("trend") is used to challenge and potentially dismiss non-binary identities as a form of fiction, while unexplored and unaccounted in relation to binary masculine or feminine identities and their relative social privileges. This view shows a bias toward a binary model, but also represents an awareness of the deep implications of non-binary identities for the BSGI and the challenges it poses to current models.

Understanding of Transgender Identities

My question about the changing criteria that define gender incongruence in the DSM-5 was a way to engage the interviewees in a conversation about transgender identity and gender identity overall as shaped by both biological factors and socio-cultural factors, moving away from the biologically deterministic models of the BSGI.

Researcher A demonstrated a complex understanding of transgender identity. Researcher A takes into account self-determination as a first component: "we ask the patient "what

do you call your gender identity?".". The second component is forms of distress stemming from the self, and the third is forms of distress stemming from the social environment: "in what way does that gender identity mismatch or distress you when you look at yourself or think of your own body? (…) how much does the distress that surrounding sees you, misgenders you, or belonging to that gender role?." Another aspect is a critique of othering and of the distinction between cis and trans: "we should stop seeing trans people as exotic or special, where there are more things in common." Researcher A situates gender identity and perceptions of the body in relation to normative ideas of masculinity and femininity: "the way you think about your body is reflected from what society norms. Like, old female bodies are not nice, but 25-year-old females in a cis heteronormative world are, so. It's probably impossible to think, to separate them and to even know. Am I unhappy of my breast size due to that I'm really unhappy about them or that there are society norms for breast size?."

Researcher C, has an understanding of transgender identities tied to diagnostic categories and biological factors. I urged the researcher to take into account the historical and cultural dimension and think about "how, before there was something called trans, did people who now would be understood as such, live, and what ways of understanding themselves did they have?." In their reaction, the researcher first focuses on the role of technology and techniques as means to express gender identity, such as "medical possibilities" and "the internet," where "you can photoshop yourself until it fits the identity you have actually." This follows a logic of "true" and "fake" identities and the sense of a prior gender identity as stemming from the self. But researcher C then elaborated on the development of cis or transgender identities in a triad of "sexual maturation" and "interest in the other, usually in the opposite sex," "reorientation with social changes from family to peers" and "thinking about yourself, who am I, not only in terms of boy or girl, but also in terms of who am I in this world." This understanding of transgender identities, while still focused on the cis and trans distinction is much more complex than the definitions found in the BSGI and shows many possibilities for introducing contextual factors as constitutive of gender identity development.

ON EPISTEMIC INJUSTICE IN BRAIN STUDIES OF (TRANS)GENDER IDENTITY

In this section, I finally address the central question of my paper "Which forms of epistemic injustice can be identified in the conceptualization of gender identity in the brain studies of (trans)gender identity?." Before presenting my conclusions, certain remarks on the validity of this research are due. My analysis is based on my open alignment with biosocial, developmental, mosaicist, contextualist and depathologizing approaches, I am not a neutral observer but a situated agent. Therefore, the whole project is founded on acceptance of feminist and social epistemologies of science. Regarding my analysis of the conceptualization of gender identity in BSGI, the results are limited to the sample and can't be automatically extrapolated to represent similar BSGI. Regarding the expert interviews, it needs to be taken into account that these types of interviews are not meant to provide results to be generalized. My assessment of the interviewees' epistemic attitudes only holds true, in a strict sense, in the context of the dialogue which unfolded in the interview and cannot be assumed to characterize past or future positions of the interviewees. Regarding the assessment of epistemic attitudes, the categories of analysis offer a margin for interpretation. Perceptions of epistemic behaviors might vary between different analysts, as well as judgments of relevance of different dimensions. Despite these restrictions, the findings of my analysis are consistent and relevant enough to open up a critical discussion of the conceptualization practices identified in the studies.

Testimonial Injustice in Published Brain Studies of (Trans)Gender Identity

In the early published studies biosocial, developmental, mosaicist, contextualist and depathologizing approaches were completely ignored. Taking into account the direct relevance of these approaches as well as the responsibility of researchers to engage with the current state of knowledge on the topic of research, I argue that the early published papers represent a form of active silencing or blocking of these lines of work. The exclusion of this knowledge is connected to the conceptual problems identified in the studies, namely internal conceptual inconsistency, hermeneutical misconception and the upholding of questionable paradigms. The epistemic injustice involved in the exclusion of counter-hegemonic positions represents at the same time a failure of the epistemic system of empirical scientific work.

For the recent studies, I want to acknowledge that while biosocial researchers were not explicitly acknowledged, the CD and SR/BP hypotheses mention environmental and experiential factors. However, this is not reflected in changes in research design nor in an adequate theoretical discussion, which is why I argue that the testimonial exclusion of scientists working on biosocial approaches of sex/gender is perpetuated in the more recent studies, but acknowledge that the theoretical opening holds the possibility of a future correction. Also, while the criteria for gender dysphoria in the DSM-5 are incorporated, there is no engagement with the conceptual implications of the changes. Instead, the CD hypothesis relies on Blanchard's typology of trans, and the SR/BP hypothesis erases gender as a dimension.

The changes introduced in the recent studies show that the epistemic system of the BSGI has a selective sensitivity. It responds to dissonance between predicted findings and observed findings, giving impetus to the search for new theoretical references and modification of the O/A framework. Despite these developments, the problems of conceptual inconsistency, hermeneutical fallacy and questionable paradigms persist.

But can the epistemic agents involved in the BSGI be said to benefit from the exclusion of biosocial, developmental, mosaicist, contextualist and depathologizing approaches? To answer this question, it is helpful to consider Latour's account of the establishment of scientific facts. He shows the facts are established as such through the uptake and use by

other researchers to ground further claims. In this sense, the testimonial silencing of alternative approaches has two effects. First, it prevents a challenging of the claims upon which the BSGI are built, strengthening the research's value in terms of credibility. This results in relative career advancement and greater access to grants, for example. Second, through silencing, the BSGI actively work toward an exclusion of the positions of the alternative approaches as scientifically relevant. These effects combined make it possible that the epistemic agents involved in the BSGI suffer no loss of epistemic status or credibility despite the deficiencies of the knowledge produced. Further, the epistemic agents of the BSGI can generate more studies and results through not engaging with complex conceptual questions, which would be a time-intense form of work with less revenue than the production of empirical data. From this examination, I conclude that the testimonial silencing and lack of sensitivity toward biosocial, developmental, mosaicist, contextualist, and depathologizing approaches in the published studies of the BSGI represent a case of epistemic injustice that needs to be addressed.

Testimonial Injustice in the Research Process of Brain Studies of (Trans)Gender Identity

The first insight from the interviews on the question of testimonial injustice against biosocial, developmental, mosaicist, contextualist, and depathologizing approaches in the BSGI is the visibility of different positions of the researchers involved in the BSGI. The epistemic attitudes toward the alternative approaches ranged from acceptance and familiarity, favorable assessments and openness, to resistance and blocking. Further, the interviews also showed the role of the hierarchical organization of research teams in the suppression of dissent and alternative approaches. This is enabled by concentration of the decision-making power in the role of the principal investigator, who is also the receiver of funds and the owner of research data. The fact that epistemic agents directly involved in the BSGI, such as researcher A, are familiar and favorable to counter-hegemonic approaches, or open to engage with them, such as researcher C, suggests that one mechanism of the epistemic injustice is through epistemic devaluation of dissenting voices within research teams, especially the ones of subordinated researchers.

The second insight from the interviews was the identification of specific instances of harmful testimonial practices against proponents of counter-hegemonic approaches, such as the refusal to collaborate reported by researcher C or their active devaluation as unscientific by researcher B. Both instances are enactments of willful ignorance, of not wanting to know. In the first case, the knowledge that could be gained through the collaboration is blocked. In the second case, there is a need to suppress certain knowledge in order to maintain an epistemic situation, despite the dissonance embedded in this suppression.

A third insight was that besides targeted forms of exclusion, there are more diffuse forms of testimonial exclusion at work in the BSGI. One instance is the ignorance of social theories of sex and gender exemplified by researcher B and C, showing the insensitivity of the epistemic system to the exclusion of whole disciplines. A second instance is the devaluation of the claims of epistemic agents that were perceived as motivated by political interests, such as feminist scientists, "militant" or "activist" researchers. Noting that only counter-hegemonic positions challenging the status quo of society are perceived as political, while positions resisting change are perceived as neutral and capable of objectivity, this exclusion indicates a different kind of failure of the epistemic system of the BSGI. It is an epistemic system that is not able to reflect and integrate into its knowledge production process the positionality of its researchers in relation to their topic of research. It fails to account for the ways in which the situatedness of the researchers shapes perceptions, categories, hypothesis or interpretations. This critique has been also raised from within the field of neuroscience of gender identity (see Walsh, 2015).

I argue that the active and targeted exclusions of counter-hegemonic approaches and their epistemic agents is enabled and promoted by systemic factors related to the organization of scientific work such as the projectification of science, which tends "to privilege already codified over novel, uncertain knowledge; theory and application of methodology over building upon it; hypothesis testing over creation or, in short, "normal science" over revolutionary, risky or unorthodox science" (Torka, 2018, p. 61). On this basis, strategic epistemic practices can be suggested toward developing a higher sensitivity toward the diffuse and targeted exclusion of alternative and counter-hegemonic approaches: individual openness, transparency of internal disagreements and multiplicity of interpretations within research teams, the promotion of exchange across disciplines, building inter- and transdisciplinary networks and collaborations centered on a common question, open data initiatives, and the reassessment of funding and review criteria in order to promote theoretical innovation and sensitivity to the exclusion of marginalized or counter-hegemonic approaches.

Underlying Hermeneutical Deficiencies in the Brain Studies of (Trans)Gender Identity

One hermeneutical deficiency of the BSGI stems from the suppression of critical epistemologies in biology and natural sciences. These critical epistemologies have been informed by an acknowledgment of the social embeddedness of research and knowledge, as has been shown by works from history and sociology of science. It is only through the suppression of these works that the internal/external division between science and society can be upheld. Critical epistemologies also challenge the notion of "nature" as that which is really true, and as opposed to phenomena that are seen as socially constituted. In order to move toward a more epistemically just situation it is important to establish an understanding of science that is able to acknowledge the situatedness of research and the hybrid social and biological constitution of phenomena.

A second hermeneutical deficiency results from the historic epistemic oppression of trans people as epistemic agents. The current regime of legal and diagnostic procedures is built on a denial of credibility of trans people regarding their own gender identities. Despite the move toward depathologization

of medical and clinical vocabulary, the epistemic oppression of trans people persists in the dependence on medical experts. The BSGI are not only embedded in this epistemic situation, they also enact this same devaluation of trans people's credibility. This is exemplified in the different assessment procedures to determine the gender identity of trans and cis participants, as well as the difficulties to acknowledge non-binary identities as a real phenomenon. The historical suppression of trans and gender diverse people's statements regarding their gender identity has created a hermeneutical system that lacks the resources to make sense of the existence of trans and gender diverse people, and that is inadequate to understand gender identity in all its expressions.

I argue that the instances of testimonial injustice against the epistemic agents of alternative approaches in the BSGI are secondary to the historic epistemic oppression of trans and gender variant people, and to the suppression of critical epistemologies. These suppressions lead to hermeneutical deficiencies that cause the BSGI's epistemic system in its current practices and structures to generate deficient knowledge about gender identities. In order to move toward an epistemically just situation, changes in science education are necessary, such as the introduction of pluralist and critical epistemologies. Further, the administratively inscribed epistemic devaluation of trans people in procedures for legal name and sex change and access to trans healthcare needs to be dismantled. Only then, by ensuring the autonomy of trans people from medical and scientific authorities in their access to fundamental rights and involving them in the research process, can a situation be generated in which trans people regain epistemic agency and trust.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

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

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HYPOTHESIS AND THEORY
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A Dynamic Systems Framework for Gender/Sex Development: From Sensory Input in Infancy to Subjective Certainty in Toddlerhood

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From birth to 15 months infants and caregivers form a fundamentally intersubjective, dyadic unit within which the infant's ability to recognize gender/sex in the world develops. Between about 18 and 36 months the infant accumulates an increasingly clear and subjective sense of self as female or male. We know little about how the precursors to gender/sex identity form during the intersubjective period, nor how they transform into an independent sense of self by 3 years of age. In this Theory and Hypothesis article I offer a general framework for thinking about this problem. I propose that through repetition and patterning, the dyadic interactions in which infants and caregivers engage imbue the infant with an embodied, i.e., sensori-motor understanding of gender/sex. During this developmental period (which I label Phase 1) gender/sex is primarily an intersubjective project. From 15 to 18 months (which I label Phase 2) there are few reports of newly appearing gender/sex behavioral differences, and I hypothesize that this absence reflects a period of developmental instability during which there is a transition from gender/sex as primarily inter-subjective to gender/sex as primarily subjective. Beginning at 18 months (i.e., the start of Phase 3), a toddler's subjective sense of self as having a gender/sex emerges, and it solidifies by 3 years of age. I propose a dynamic systems perspective to track how infants first assimilate gender/sex information during the intersubjective period (birth to 15 months); then explore what changes might occur during a hypothesized phase transition (15 to 18 months), and finally, review the emergence and initial stabilization of individual subjectivity-the period from 18 to 36 months. The critical questions explored focus on how to model and translate data from very different experimental disciplines, especially neuroscience, physiology, developmental psychology and cognitive development. I close by proposing the formation of a research consortium on gender/sex development during the first 3 years after birth.

Keywords: gender/sex, infancy, dynamic systems, sensory input, subjective outcome, interdisciplinary consortium

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INTRODUCTION

Overview

By 3 years of age, most children-at least those who grow up in Western Educated Industrialized, Rich, Democratic i.e., WEIRD cultures (Henrich et al., 2010)- express a subjective gender/sex identity (see section "A Note on the Meaning and Use of Gender/Sex"). Researchers infer this identity and measure its strength by examining preferences and behaviors understood in WEIRD societies to be more or less typical of boys compared to girls (Zucker, 2005; Zucker and Wood, 2011). Caregivers control infant gender/sex expression by choosing clothing, hairstyles and jewelry on their child's behalf, but by age three, children enact significant agency in choice of toys, clothing, and playmates (Todd et al., 2018). Gender/sex-related toy preferences do not appear until sometime during the 2nd year. For example, in one multi-age cross-sectional study, researchers found that infants showed no visual preference when shown matched pairs of vehicles and dolls, but that by 18 months toddlers showed a gender/sex-biased preference for these items and the girls in the study associated certain toys with a particular gender/sex (Serbin et al., 2001). Gender/sex self-knowledge and concomitant preferences and behaviors appear in bits and pieces over time. In another study of 2 year olds, 67 percent could label themselves as their assigned gender/sex although they were less successful at similarly labeling other children (54 percent), toys (23 percent), or activities (13 percent) (Campbell et al., 2002). This sequence suggests that self-identity at least partially precedes the understanding and/or enactment of gender/sex-differentiated preferences and behaviors (Ruble et al., 2010). As one additional example, using a longitudinal design of 17 and 21 month olds, researchers noted that at both ages, toddlers had gender/sex related preferences for play with trucks and dolls. They had no gender/sex related preferences, however, for other stereotyped activities such as tea sets, brush and comb sets and blocks. The differences, present at 17 months, increased in size by 21 months. In this study the investigators related the acquisition of gender/sex category words such as "boy" and "girl" to the increase in differences in play preferences between 17 and 21 months (Zosuls et al., 2009).

How can we explain this acquisition of gender/sex subjectivity which seems to be absent before about 15 months, but that apparently snaps into place during the next 9 months, and stabilizes during the third year of development? Two theoretical approaches to understanding the strength of gender/sex identity at age three predominate in the research literature. The first emphasizes biological underpinnings. Based on studies of children who had been exposed to unusually high levels of androgens or estrogens during fetal development, or studies that correlate levels of amniotic hormones and later play behavior, or studies of identity formation in children with a severe intersex condition called cloacal exstrophy, a number of researchers have concluded that fetal hormonal environments contribute strongly to gender/sex identity development (Collaer and Hines, 1995; Hines et al., 2002; Reiner and Kropp, 2004; Reiner, 2005; Auyeung et al., 2009; Lillard, 2015). More recently, even the authors of some of these earlier papers linking hormones and gender/sex development have acknowledged the weakness of the evidence supporting a strong theory (direct and/or linear) of hormonal causation of gender/sex differences in childhood behavior (Jordan-Young, 2010; Hines et al., 2016; Xiong et al., 2020). Strong conclusions from other authors still exist, though. For example one recent publication claimed that "Gender identity is biologically conferred during the middle trimester of pregnancy" and referred to "gender identity … as biological, innate, and immutable" p. 33 (O'Hanlan et al., 2018).

Beyond the sketchiness of the evidence, however, I find a "biological underpinnings" approach deeply unsatisfying mainly because it does not tell a developmental story. Studies infer or directly measure hormone levels at time A, and then often years later assess some aspect of behavior (time B), as if the events of time A and the behaviors of time B are directly and linearly linked, while the events of the intervening years remain unmentioned and apparently irrelevant to the outcome.

The second predominating theoretical approach comes from researchers in developmental, cognitive, and social learning psychology. These scholars offer a more nuanced narrative. Ruble, Martin, and Berenbaum (Ruble et al., 2006) discussed the possible causes of developmental change, as seen through the combined lenses of biology, cognitive development, and socialization theory. Building on the earlier work of Huston (1983, 1985), Ruble et al. presented a matrix of constructs. The matrix included biological, behavioral and cultural versus content areas cross-referenced with "biological gender," "activities and interests," "personal-social attributes," "gender-based social relationships," and "stylistic and symbolic content." The assembly and organization of this large body of work was heroic and laid a necessary foundation for the ideas I present in this article, but their approach still uses a static theoretical framework. First, most publications within this body of research seem to consider gender/sex identity to be a fixed "thing" apparently located somewhere in the body or brain [see section "Discussion" in Fausto-Sterling et al. (2020)]. And, even though this literature offers a developmental timeline and more nuanced details of when components of this "thing" appear, in my opinion, this body of work does not have a working theory that interweaves the constructs presented in little compartments in the "matrix of gender-typing" table (p. 859) into a narrative of dynamic and continuous development.

Some of the authors cited in the previous paragraphs now recognize dynamic systems theory as an important theoretical and research approach. Hines, for example, noted that "One appealing aspect of a developmental systems perspective is that it can obviate the misleading nature versus nurture debate." p. 35 (Hines, 2015) while Martin and Ruble emphasize that dynamic systems theory provides "more nuanced views of gender at different timescales." By timescales they intend on the one hand explaining long term developmental changes (time scale of years) in gender identity from infancy to childhood, adolescence and adulthood, and on the other hand describing how gender plays out in short term interactions (time scale of minutes). But to date these authors have not taken on the challenge of outlining a multi-level, dynamic, and developmental systems theory of early gender/sex development.

A wealth of publications in the biosciences and psychology use and advocate for dynamic systems theory (DST) (Oyama, 1985, 2000; Smith and Thelen, 1993a,b). Several key ideas–self organization, complexity, embodiment, continuity in time and dynamic stability–lie at the heart of DST (Thelen, 2005). *Self organization*, a well-known phenomenon in biology, refers to the apparently spontaneous emergence of pattern or order due to the stabilization of internal processes, rather than an external directive force. Self-organizing systems are often complex, heterogeneous, and encompass multiple levels of biological and social organization (Kelso, 1995; Warren, 2006). Their study requires understanding short-term (e.g., neural events of a specific memory formation, or the visual and vocal interactions between a caregiver and child during a brief exchange), mid-term (the development of coordinated play–see for example de Barbaro et al., 2013b) – and long-term dynamics (see Thelen, 2000 for an integrated discussion of short, mid and long term dynamics). In one discussion of *complexity*, Thelen wrote "Human behavior is the product of many interacting parts that work together to produce a coherent pattern under particular task, social and environmental constraints" (p. 261) (Thelen, 2005). Behaviors, in this conceptualization are not caused by a single driving force–be it hormones or parental directive–but are the collective property of a complex system.

Dynamic systems theorists often discuss *embodiment* as a critical component of complexity. An embodied phenomenon is one that "emerges in the interaction of an organism with an environment . . . as a result of sensory-motor activity." (p. 278) (Smith, 2005). Thelen wrote that embodied cognition emerges from and remains enmeshed within the body's interaction with the world (Thelen, 2000). By extension, I theorize that gender/sex identity "depends on the kinds of experiences that come from having a body with particular perceptual and motor capabilities that are inseparably linked and that together form the matrix within which reasoning, memory, emotion, language, and all other aspects of mental life are embedded" (p. 5) (Thelen, 2000). In this formulation, gender/sex is not an abstract thing that resides somewhere in the mind or brain, but is a dynamic process that emerges from in-the-moment experiences over time. Once in a state of *dynamic stability* gender/sex identity seems independent and unattached from the processes that produced it. But prior to achieving such stability any emerging system may experience instability as it transits from a previously stable state to a new and different one. Change here is *non-linear* and involves a measurable *phase shift* (Thelen and Ulrich, 1991; Thelen and Smith, 2006). A central feature of DST is that new behaviors are linked *continuously in time* to older phenomena and that to understand the origins of a behavior of interest, one must start before it exists, watch it emerge and figure out the key systems components involved in its production.

A Note on the Meaning and Use of Gender/Sex

The terms sex and gender imply an additive causal model that is (biology plus culture) usually with some allowance for "interaction" as a third, poorly articulated term. Unger and Crawford pointed out the difficulty with the sex versus gender terminology when they wrote "With the possible exception of very specific reproductive behaviors, however, it is not possible to determine how much of a particular trait or behavior is influenced by biological versus social factors. . ." (p. 124) (Unger and Crawford, 1993).

Responding to such conceptual difficulties, in a research project that focused on hormones, which are most often listed as a feature of "sex," van Anders and Dunn introduced the term gender/sex "because," they wrote, "differences cannot knowingly be attributed to biology or gender socialization" (p. 207) (van Anders and Dunn, 2009). van Anders defined gender/sex as pertaining to "whole people/identities and/or aspects of women, men and people that relate to identity and/or cannot really be sourced specifically to sex or gender" [Table 2 in van Anders (2015)]. Fausto-Sterling, Kaiser, and Pitts-Taylor used the term sex/gender to connote body-based characteristics that are shaped by gendered social interactions (Kaiser et al., 2007; Fausto-Sterling, 2012; Kaiser, 2012; Pitts-Taylor, 2016). However, to maintain consistency with the way the term was initially introduced, I now prefer the term *gender/sex*. Furthermore, in mainstream psychology the term has begun to catch on (Hyde et al., 2018).

The Phases of Gender/Sex Development

Gender/sex development bears the hallmarks of a dynamic system. In previous work, based on a review of developmental psychology literature, my colleagues and I divided gender/sex emergence into three phases (Fausto-Sterling, 2020; Fausto-Sterling et al., 2020). The first, which spans the period from birth (or before) through about 14 months, involves the acquisition of gender/sex recognition skills. For example, between the ages of 6 to 8 months infants demonstrate the ability to distinguish between male and female voice recordings. By 9 months they can differentiate pictures of male from those of female faces. These skills, a compilation of which may be found in Fausto-Sterling et al. (2012), reflect an increasing ability to recognize and remember repeated elements in the environment. The second is a period of instability during which the infant assimilates earlier embodied learning during a period when he or she also acquires language and independent mobility. As described in the opening paragraph, gender/sex preferences start to appear but are difficult to measure. During the third phase, identity, measurable by specific behaviors and preferences, and the ability to indicate group belonging becomes evident and stable. In the next three sections of this essay I lay out some of the known parameters for each of these phases.

Phase 1

I have argued (Fausto-Sterling 2019) that sensorimotor experiences register in the body, both as cognitive and neuromuscular memory (Fausto-Sterling, 2019) and make this argument more explicitly in **Figure 1** of the current essay. During Phase 1 the infant's motor and sensory development integrates the data set available for recognizing and embodying gender/sex. For example, at 3–5 months, when infants lie on their backs, or are held, facing in or facing out, by an adult, or

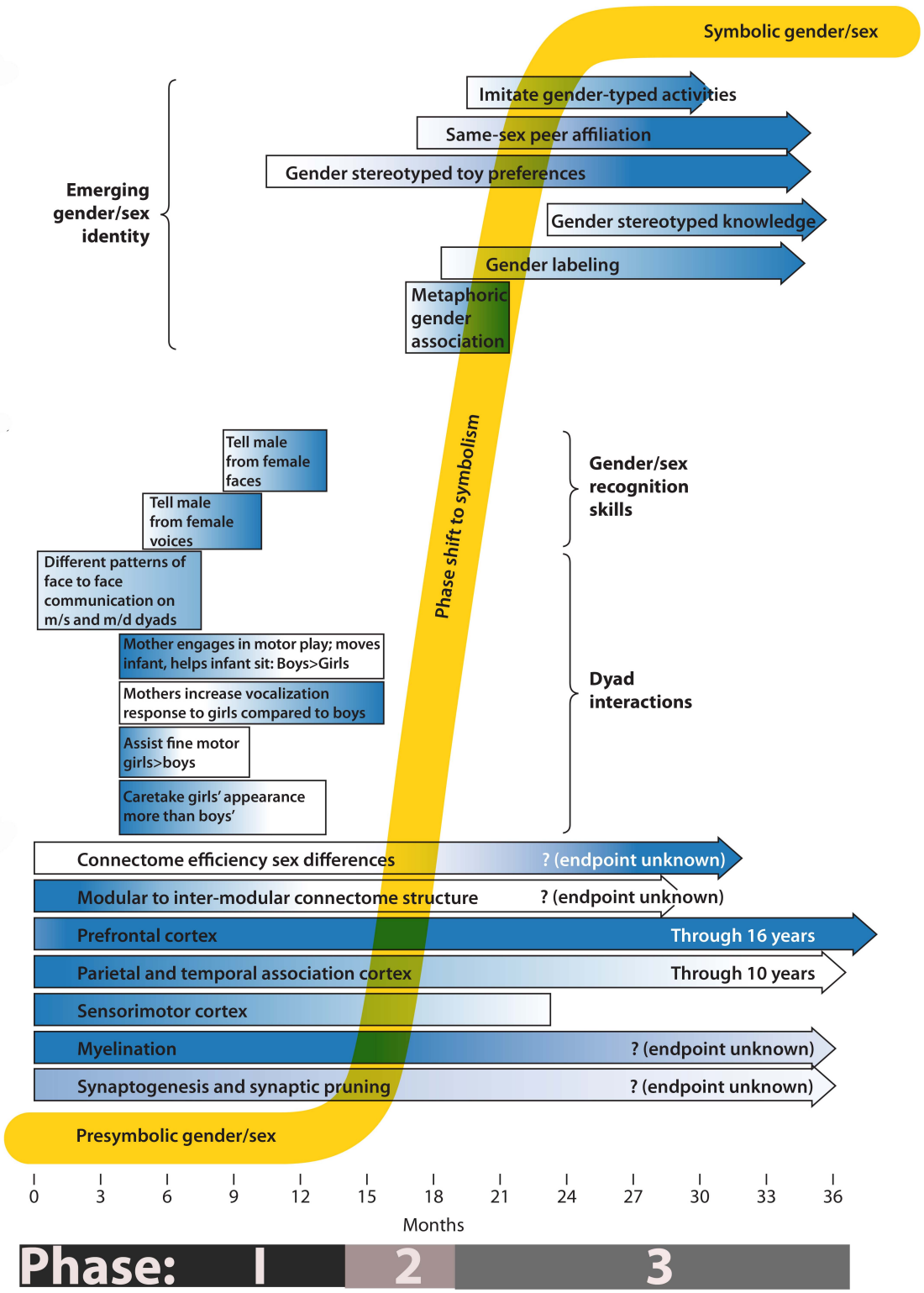

FIGURE 1 | Phases of gender/sex development. The composite timeline illustrates systems undergoing change from birth to 3 years. Longitudinal bars show gradients of activity, from light (low activity) to dark (high activity). The lower third of the drawing emphasizes known changes in the growth and development of the nervous system. The middle third indicates the timing of gender/sex skill acquisition and of known gender/sex differences in care-giver/infant dyad interactions. The top third indicates the emergence of behaviors associated with subjective gender/sex identity. For a definition and measure of connectome efficiency please refer to reference (DiPietro and Voegtline, 2015).

are bathed and diapered, they experience touch from another person more frequently than they voluntarily reach out and touch an object, surface or person. On the caregiver side of the dyad, features of touch such as frequency, duration, pressure, and association with speech or play, etc. may differ depending on the gender/sex of the person who touches and on the perceived gender/sex of the infant. On the infant side, babies can differentiate between adult male and female voices and faces.

Thus, a baby's sensory input depends on more than its own sensorimotor abilities. Indeed, during the period of physical helplessness, adults provide most of the visual, touch, and sound input. Even at a very young infant age, this provision is differentiated by gender/sex. We have reported (Fausto-Sterling et al., 2020), for example, that mothers of 3-month old infants engage in motor social play with sons for longer durations than daughters, that they help sons sit more frequently than daughters, and that they shift sons' positions more frequently and for longer time periods than daughters." We also found that mothers of 3–6 month old sons touched them more frequently than did mothers of daughters (Fausto-Sterling et al., 2015), and reported a sex by age interaction (for months 3–12) for both instrumental touch (e.g., moving a child from one spot to another) and stimulatory touch. Finally, we and others have reported perceived sex of infant-differentiated frequencies of infant-directed maternal vocalization (Sung et al., 2013; Johnson et al., 2014).

In sum, gender/sex embodiment in the first 14 months involves the dynamics of self-development of motor and sensory skills, their use in absorbing the experiential data presented to the infant, and the creation of the environment by primary caregivers. This creation involves the physical setting (room décor, toys, and clothing) but also the intimacies of physical touch, imposed movement, and sound. Later in this article I will return to Phase 1 to recount what researchers in the disciplines of neuroscience, physiology and developmental psychology already know from their particular disciplinary point of view about development more generally and gender/sex embodiment more specifically.

Phase 2

Between approximately 15 and 18 months I hypothesize that the infant shifts (Phase 2) from recording intersubjectively generated, presymbolic gender/sex knowledge, to producing embodied, symbolically understood and expressed gender/sex identity. There are fewer reported findings about gender/sex development in the time slice between 15 and 18 months see especially (Fausto-Sterling et al., 2012; Figure 2) a result, probably, of increased variability during this time frame. In this S-shaped trajectory, Phase 1 represents a period in which the underpinnings of subjective gender/sex-related sensory and cognitive data slowly accrete; but gender/sex itself is not visible by any measures at researchers' disposal. I hypothesize that Phase 2, entails a relatively chaotic period when high individual variability and a disruption of the stable period of presymbolic accretion makes measuring group differences quite difficult (Thelen, 2005). Starting at about 18 months, however, a subjective sense of gender/sex and the preferences and behaviors that accompany that sense start to emerge. Phase 3, which continues to at least 3 years (and actually beyond, but not covered in this paper), is the period during which subjective gender/sex stabilizes and deepens.

Phase 3

Between 18 and 36 months toddlers consolidate and stabilize gender/sex self-knowledge and gender/sex knowledge of the world. Their sense of self as having a gender/sex identity becomes internalized, although intersubjective feedback and stabilization contributes to identity throughout the life cycle. From 18 months on children express gender/sex knowledge symbolically, for example, via a pink/blue color scheme and clothing or play preferences designated within a culture as gender/sex differentiated (Eichstedt et al., 2002). Ruble, Lurye, and Zozuls write about the rigidity with which some children in the 3–6 years old age range insist on using gender symbols and preferences such as clothing, hair style, friendships and play styles. Ruble and colleagues associate acquiring gender/sex specific language with this active period of gender/sex self socialization. "Girls' love of pink, frilly dresses" they write "may be viewed as a kind of obsession linked to developing knowledge about social categories." (p. 4) (Ruble et al., 2010). JeongMee Yoon's Pink and Blue Project provides one artist's vision of this obsession (Yoon, 2005).

Organization of This Paper

In the section entitled "The Challenges: Synthesizing Theories and Investigatory Approaches to Explicating Gender/Sex Identity Development", I review some of the things we do–and do not–know about underlying systems which most likely support gender/sex emergence, and discuss the challenges of understanding how infants integrate events that occur on different time scales and at different levels of biological organization. I also review some of what we know about how the infant itself integrates sensory and social inputs *en route* to becoming an independent subject. Finally, I suggest possible approaches to surmounting the challenges researchers face in synthesizing myriad theories and empirical approaches to the study of early gender/sex development.

STUDYING GENDER/SEX AS A DYNAMIC SYSTEM REQUIRES INTERDISCIPLINARITY

Disciplines and Biological Scale

Figure 1 summarizes some of the processes important to understanding gender/sex formation during the first 3 years of development. At birth, or even prenatally (Moon et al., 2013), infants record sensorimotor information in a "non-verbal, imagistic, acoustic, visceral, or temporal mode" (Beebe and Lachmann, 1994) (p. 132). The information diagrammed in **Figure 1** describes events and processes that occur at markedly different levels of biological scale. During the first few months of Phase 1, for example, notable changes take place at the cellular and intercellular level (bars indicating specific aspects of brain development). Complex parental behaviors and developing

infant cognition–which occur at higher levels of organization than the establishment of inter-neuronal and neuro-muscular connectivity-become features of the middle and later parts of Phase 1. During Phase 2 I propose that infants integrate the different levels of information acquired during Phase 1, allowing qualitatively new traits to appear. During Phase 3 a full presentation of self as having a specific gender/sex appears. This self-presentation draws on cultural symbols such as hair and clothing styles, toy preferences, etc. It seems sudden and new. However, as a developmental systems theorist, I view it as an emergent property, a qualitative shift that results from the quantitative accumulation (at the cellular, intercellular, inter-organ, and intersubjective levels) of body knowledge about gender/sex. **Figure 1** serves as a guide for the discussion of relevant physiological, dyadic and autonomous behaviors that mark the presymbolic, transitional, and symbolic phases of gender/sex development. I note that I have drawn on a literature that comes almost exclusively from studies of white, middle class, European-origin families, and that patterns of gender/sex-related behaviors and interests discussed here are not universal (Lew-Levy et al., 2020).

Neuroscience

Neuroscientist Lise Eliot wrote, "Toy play may look instinctive in children–as when we see toddlers cuddling a doll or pushing a toy truck across the floor–but every piece of such actions requires learning and tuning of neural circuits to the specific sensory, motor, spatial, social, cultural, and motivational demands of both object and environment" (p. 171) (Eliot, 2018). To explore Eliot's remark, I selectively review findings from the neurosciences that are relevant to the presymbolic embodiment of gender/sex.

Even before birth, synaptic connections involved with sensory and related motor activities proliferate exuberantly. As neurons attain peak bushiness, they gain specificity by pruning some connections and strengthening others (Elman et al., 1996). Nervous transmission also becomes more efficient and accurate when long nerve fibers gain electrical insulation via myelination. As represented in the bottom third of **Figure 1**, synaptogenesis and synaptic pruning is especially active during the first year of development. The first 6 months are particularly important for the development of the sensorimotor, prefrontal, parietal, and association cortices (Thompson and Nelson, 2001), while intense myelination occurs during the first year of infancy. [For an overview of human brain development see Zelazo et al. (2010)]. Critical to the idea that gender/sex–at least initially–is a process requiring both dyadic interactions and interactions between infants and objects in its world is the fact that specific synaptic connections form under the influence of specific experiences. While synaptic plasticity and experience-related myelination (Forbes and Gallo, 2017) are well demonstrated in animal models, it is more difficult to perform exacting experiments in humans (Marshall, 2015; Mansvelder et al., 2019). Nevertheless, using non-invasive measurements of brain activity has lead researchers to state unequivocally that "The experiences children have literally shape their brains" [p. 3 (Meltzoff and Kuhl, 2016)]. Parsons et al., review the substantial literature on postnatal brain development in human infants including the critical importance to brain development of social and sensory stimuli (Parsons et al., 2010).

Despite the well accepted overview of events in the developing infant brain, it is difficult to directly link anatomy with specific behaviors and functions (Gao et al., 2009, 2017). Parsons et al. (2010) have published a timeline that correlates infant age with emerging abilities (e.g., face-processing at 2–8 months or joint attention at 14–18 months) and they note what brain regions seem to be associated with these abilities (Parsons et al., 2010). Knowledge of such associations increasingly derive from the identification of neural circuits/networks. Identifying circuits and higher order networks, and assigning to them specific roles in brain function and emergent behavior is an area of active research and theoretical consideration (Friston, 2011; Kelso et al., 2013). Findings to date suggest that primary sensorimotor and visual areas are more fully developed, but that systems such as the limbic, frontoparietal (attentional, problem-solving, working memory), and the default network are highly variable among individuals at birth (Xu et al., 2018), decline in activity but develop more fully by the end of the first year. Xu and colleagues (2018) suggest that this pattern of initial high variability may be due to what they call a lower memory load before birth.

We know little about gender/sex structural differences in the central nervous systems of infants and children. Although Giedd et al., documented differences in brain structure between boys and girls as young as 4 years old (Giedd et al., 1997; Gogtay et al., 2004; Lenroot et al., 2007), no data exist for infants and toddlers. Perhaps, though, there is a story to be explored at the level of nervous system functioning and the connectome. One publication reported no differences between males and females in the efficiency of either global or local information transfer in two-week olds and 1-year olds. However, both local and global brain network efficiency was reported to be significantly greater in male compared to female 2-year olds (Yap et al., 2011), the time point that marks the end of my proposed phase transition to symbolism, and the early expression of differences in preferences and behaviors. This finding is thought-provoking, but comes from a single study on a small sample, and thus requires replication and expansion. Even then it will remain to be seen if any gender/sex differences in connectome function relate to the behaviors and preferences that at age three reveal subjective identity formation.

Physiology

For reasons of space and clarity, **Figure 1** does not cover physiological development. But gaining control of autonomic physiological functions such as temperature regulation, sleep cycles, and states of arousal is a significant task facing young infants. The development of physiological self-regulation has been extensively studied (Feldman, 2003, 2007; DiPietro and Voegtline, 2015). Porges and Furman (2011) describe a time line for the early development of the autonomic (vagal) nervous system which initially uses feeding (visceral) circuits to regulate basic functions such as respiration, but by 6 months regulates autonomic states by social engagement (Porges and Furman, 2011).

Of particular interest are findings of infant and parent gender/sex related differences of arousal-stimulating parental behaviors. Parental play stimulation differences according to infant sex in early infancy seem only rarely to have been studied (Zosuls and Ruble, 2018). Instead, with the exception of Korner's analysis (Korner, 1974), the existing literature focuses on bonding and dyad synchrony, defined as a correlation between one partner's behavior and the other's response within a defined period of time (usually on the order of milliseconds or seconds). For example, Feldman (2003) studied levels of synchrony and patterns of arousal (using a 3-level arousal scale in which high arousal was positive and energetic) in mother-daughter, mother-son, father-daughter and father-son dyads in 5-month-old infants. She observed that same-sex dyads achieved greater synchrony than other-sex dyads. Fathers' play sessions tended to reach a peak of arousal one or more times per session. This contrasted with mothers, who in 44% of the play sessions with daughters and 35% for sons had no arousal peak.

Developmental Psychology/Cognitive Development

Gender/sex recognition skills

As depicted in **Figure 1**, Phase 1 includes the appearance of cognitive skills that we have named gender/sex recognition skills. For example, at 5 and 7 months infants cannot categorically distinguish between male and female faces, but by 9 months they have acquired this skill (Leinbach and Fagot, 1993). They have, by then, also gained the ability to associate female voices with female faces (Poulin-Dubois et al., 1994). One study found that preference for male or female faces in five-month olds varied with the sex of the primary caregiver (Quinn et al., 2002). While researchers collect connectomic data using magnetic resonance brain scans, they use visual or aural habituation studies to collect information about prelinguistic, cognitive gender/sex skills. I am presuming that these operate at a scale above the level of the connectome, but that they reflect connectome function. Designing new studies that look for the emergence of gender/sex recognition skills while measuring specific brain activity, using methods that combine qualitative microanalysis at multiple levels of dyad interaction with quantitative assessment of "action arcs" over developmental time, could inform us about what areas of the brain become involved with gender recognition (moving from midscale to microscale analysis) (Kuhl and Rivera-Gaxiola, 2008; Rączaszek-Leonardi et al., 2019).

Phase 1: Dyad Interactions

Many behaviors relevant to Phase 1 involve interactions within an infant-caregiver dyad. These interactions may focus directly on one another or they may involve the infant and caregiver jointly interacting with an object such as a toy or bottle. During the first three months, for example, infants and caregivers spend a great deal of time in face-to-face communication. In one study, after the initial month, mothers, and infants communicated face to face for longer periods when the infant was on the sofa. But during month three, girls spent longer periods than boys in face to face communication when being held in their mothers' arms (see Phase 1 level B in **Figure 1** of this essay) (Lavelli and Fogel, 2002). During the first 6 months there are other findings of gender/sex differences in dyadic interactions. Fausto-Sterling et al. (2015) reported that from months 3 to 6, compared to mothers with sons, mothers of daughters more frequently adjusted their child's appearance by combing her hair, and straightening her dress or repositioning a hair ribbon or barrette. During this same time period mothers vocalized more to daughters than to sons (Sung et al., 2013). In a last example, another analysis showed that from months 3 to 6, mothers engaged in more gross motor activities with sons than with daughters and shifted sons from one position to another with greater frequency and duration than they did daughters (Fausto-Sterling et al., 2020).

What, if any, might be the effects of such differences in sensory input (during Phase 1) on the transition (during Phase 2) that results in the consolidation of subjective gender/sex (in Phase 3)? It seems likely that gender/sex differentiation of self and others is indirect, that is, it results from repeated observations and sensory interactions rather than direct instruction. If a caregiver regularly hands a plushie baseball and glove to a six-month old boy, for example, and he later expresses a desire to throw a ball, that desire does not emerge because he has received the instruction that boys throw balls. Rather it emerged within a meshwork of dyadic and triadic interactions. At 4 months, for example, infants mostly look at or manipulate a single object, usually held by the caregiver. Between 6 and 9 months, infants divide their attention between objects they themselves are holding and objects held onto by their caregiver (de Barbaro et al., 2015). By 12 months triadic attention between an adult play partner, the baby and one or more play objects has become fairly elaborate, and involves complex social exchanges (de Barbaro et al., 2013a). Throughout, caregivers offer attention-getting clues, including manipulating an object, gaze shift, and/or verbalization (Deák et al., 2017). It is within the broad sequence of developmental events that the more specific self-definitions of gender/sex emerge. Rather–as has happened up until now- than avoid studying this period because of behavioral instability, a dynamic systems analysis points to Phase 2 as exactly the period that we need to imaginatively investigate.

Such developmental processes will vary individually depending upon the pattern of adult approaches to directing attention, and individual variability in infant sensory systems. For example, my research group produced unpublished data [using the methods described in Fausto-Sterling et al. (2020)] that between 3 and 12 months of infant age, mothers manipulated objects more often and for longer duration if they were part of a mother-daughter dyad compared to a mother-son dyad. What might such a difference in adult behavior mean for the development of infant gender/sex? Does more insistent manipulation promote greater joint attention which in turn becomes a scaffold for more socially interactive patterns of play, a pattern that by age three has emerged as a group difference related to gender/sex? How does the emergence of joint attention skills relate to earlier gender/sex variations in sensory input via speech and person-to-person handling? Such questions, which offer a framework for gender/sex development during Phase 1, await empirical investigation.

One challenge is to understand whether and how the above types of gender/sex differences in dyadic behavior shape the underlying developing nervous system and produce the ability to

recognize aspects of gender/sex (what we refer to as gender/sex skills) in the infant's world. A shift in scale of the relevant events (interactive behaviors between two people or two people and an object at a macro level, inter-constructing with neural networks, connectome structure, and cellular and synaptic connections at a microlevel) is involved. Such macro to micro crossovers require varied disciplinary expertise. In the section entitled "The Challenges: Synthesizing Theories and Investigatory Approaches to Explicating Gender/Sex Identity Development", I will discuss methods that might enable productive collaborations between scientists with different disciplinary skills and who work on different scales of organismal and inter-organismal organization.

How Does an Infant Integrate Levels During Phase 1?

Think of infants as statisticians. Presented with repeated and diverse sensory inputs, they measure the frequencies of sequences of motor, visual, object and linguistic events, extracting "chunks," i.e., elements that co-occur, which they store in distributed neural networks. As they repeatedly encounter similar chunks, linked elements connect more tightly. It is through these general learning mechanisms and the cellular mechanisms involved with neural plasticity, we hypothesize, that infants extract and stabilize the structures and meanings of gender/sex, first presymbolically, and then via language and symbolism (Mareschal and Quinn, 2001; Balas et al., 2018; Gliga, 2018; Smith et al., 2018).

Smith and colleagues write that "the developing infant creates a curriculum for statistical learning" (p. 1) (Smith et al., 2018). I would modify this assertion to say that the dyad creates the curriculum. Consider videotaped sequences of a dyadic (mother-daughter) interaction collected as described in Fausto-Sterling et al. (2020). When the baby was 2.4 and 3.2 months, the mother washed her child's head. Throughout each two- to four-minute episode, she encouraged the baby to enjoy the wash, saying "doesn't that feel good? Do you want to help?" and, as she massaged the soap into her head, "Oh you smell so good." The baby smiled and tried to participate, which the mother encouraged. In these two chunks the infant combined what appeared to be pleasurable tactile sensations with a maternal narration of events. At 3.4 months, a new element appeared when the mother decided that the baby's hair was long enough to brush. She brushed gently for 13 s and said "that's not bad. All done. All done. That's pretty." The baby had been sitting on the changing table, and looking around the room, but as the mother said the first "All done," she looked directly up at her mother's face as the mother bent over her. In this third chunk, there was again a pleasant tactile sensation on the head, but this time combined with positive dyadic eye contact and maternal patter about how pretty the baby looked. Did the last chunk build on, or interact with and strengthen the preceding ones, while for the first time integrating a gendered comment ("that's pretty") into the event network? Was the establishment of a link between pleasurable touch sensations and gender/sex-weighted language underway?

Patterns of infant care structure the data chunks that infants sense and assimilate. And as those patterns become infused with gender/sex, so too does the data set or curriculum made available to the infant. At the level of neural circuits I imagine the following: as predicted by developmental systems theorists, as infants acquire motor skills such as reaching and stepping, they first call on a redundant repertoire of neural circuits (Gottlieb et al., 1998; Nishiyori et al., 2016). As they gain experience through increasingly goal-directed activities, the initially large areas of neural activation become more restricted and refined. Thus, the neural responses that underpin specific motor activities derive from both the specific goal and the experience of pursuing it. Work on multisensory, multimodal processing echoes this general idea that infants process sensory input broadly in early development, but as they gain both sensory and symbolic experience, multi-sensory perception narrows, and becomes more culturally specific (Murray et al., 2016; Cao et al., 2017). Applying these general principles to the acquisition of gender/sex, I hypothesize that at first infants perceive and turn toward any and all caregivers. With time, however, and in response to repeated patterns of care giving (both who and how), gender/sex perception develops and becomes more narrowly specific. This occurs both with regard to expectations of who the caregiver is, but also with regard to how the infant itself is touched and spoken to.

During Phase 1, early versions of cognition are already at work. These too rely on repetition and the context of exposure. The brilliant studies of Rovee-Collier and colleagues demonstrate that infants as young as 3 months can recognize and categorize objects. Furthermore, their object memory and ability to associate categories depend on regular exposure (Galluccio and Rovee-Collier, 1999, 2005; Mareschal and Quinn, 2001; Bhatt et al., 2004). The authors of a recent overview of infant memory note the following: during infancy encoding speed increases and memory duration lengthens, memory retrieval becomes more flexible, and reminders allow the infant to retrieve forgotten memories (Cuevas and Sheya, 2019). These changes "are embedded in broader socio-cultural contexts with shifting ecological demands that are in part determined by the infants themselves" (abstract) (Cuevas and Sheya, 2019). This is the same claim about infant memory that I am making about gender/sex development. Connecting back to the question of toy preference, although it does not stabilize until Phase 3, it seems likely that the kinds and numbers of toys found in an infant's environment from birth, combined with how (and how often) specific toys are offered by caregivers, and what unprompted interest the infant exhibits, produce presymbolic memory traces that the infant draws on and transforms into cognitive memory and subjective desire during Phases 2 and 3.

Several research groups that study multisensory systems emphasize (Kuhl et al., 2001, 2006; Murray et al., 2016; Lewkowicz et al., 2018) this developmental pattern of proceeding from diffuse to focused processes. This body of work involves connecting faces to specific vocalizations and language recognition. Studies suggest that both before birth and for the first 3 to 6 months after birth, infants exhibit broad, low-level responses to sound and sight stimuli. Over time, responses narrow. At first, an infant may respond fully to a non-native spoken sound; with further sensory experience, the response narrows and becomes native language specific. Lewkowicz and Ghazanfar (2009) suggested that this perceptual narrowing results from the selective elaboration of synapses

in specific response to postnatal experience (Lewkowicz and Ghazanfar, 2009). Between the ages of four to five and eight to 12 months, infants develop the abilities to "perceive, learn, and generalize recursive, hierarchical, pattern rules" (p. 1) (Lewkowicz et al., 2018). Does the infant response to gender/sex-related information follow this pattern-broad and inclusive at first, followed by a narrowing introduced by gender/sex specific experiences? If so, what forms and types of gender/sex data are most important for shaping gender/sex identity development?

From Dyads to Independent Subject: Phases 2 and 3

As infants move from Phase 1 through Phase 2 and into Phase 3, they separate from the dyad and become more independent actors. The increasing precision of motor skills such as crawling, walking and grasping is a critical animator of this separation (Campos et al., 2000). So too is the acquisition of language, which also facilitates the emergence of symbolic thought and actions (Zosuls et al., 2009; Salo et al., 2018). During Phase 2 and early Phase 3, infants transform body memory into cognitive memory. And, as these transitions accumulate during Phase 2, infants (now toddlers) enter (during early Phase 3) into a period of self-stabilization. Finally, once Phase 3 is well underway, the newly independent, subjective and (semi) autonomous sense of self stabilizes via the process of autopoiesis, defined as a network that reproduces itself, "and that also regulates the boundary conditions necessary for its ongoing existence as a network" (p. 327) (Bourgine and Stewart, 2004).

Figure 2 illustrates this dynamically stable state consolidated during Phase 3. The model is based on concepts developed by Varela (1997) and Smith and Gasser (2005). Applying to gender/sex Varela's idea that individual identities involve interactive domains, a child cannot arrive at a stable sense of self as boy or girl (upper left quadrant: *Identity*) without engaging in dyadic interactions, and specific sorts of gender/sex-specified activities (upper right-hand ellipse quadrant: *Domain of Interactions*). At the same time, self-identity in the autonomous individual (left side: *Autonomous Individual* insert) requires larger-world interactions that produce contextualized meanings about gender/sex (right side insert: *Individual in Interaction with Others and Objects*). As indicated by the large top arrow that links the Individual with the World, individuals cannot separate or articulate an understanding of self, outside of their location in the world's meanings.

Such contextualized meanings may be thought of as gender schema (Liben and Signorella, 1980; Martin and Halverson, 1981) that provide (as discussed in section "Big Theory From Other Fields") a generative model of gender/sex. The domain of interactions (upper right quadrant) starts with the absorption of bodily information as a subunit of the dyad (Beebe and Lachmann, 1994). Over time, the interactive domain expands to include interactions such as choice of clothing, toys, and peer interactions. These social interactions gain significance (**Figure 2**: lower right quadrant) as others interpret them as gender/sex. As infants observe positive, negative, or neutral valences attached to their own and others' gender/sex representations, they feed (or link) this understood significance into a self-sustaining (autopoietic) gender/sex identity system via the intentional behaviors involved with self-socialization (Varela, 1997), understood as a child's active efforts to match their own behaviors to a perceived standard (Zosuls et al., 2009, 2014; Tobin et al., 2010).

The emergence of intentional behavior moves the child from the domain of "Significance in the World" to the domain of "Operational Closure in the Individual" (**Figure 2**: lower left quadrant). In terms of gender/sex, we define operational closure as the multi-month process during which children acquire linguistic labels, the ability first to label gender/sex of self and others passively, then actively, over time acquiring the concepts of gender/sex constancy, and gender/sex stability (Fagot et al., 1985, 1986, 1992; Bem, 1989; Fagot and Leinbach, 1989, 1993; Fagot and Hagan, 1991). According to Varela, operational closure gives rise to a global property (what we call identity) without requiring "a central controller" such as an identity gene or a special group of identity brain cells.

Operational closure closes the autopoietic loop and stabilizes individual identity (upper left quadrant). **Figure 2** represents

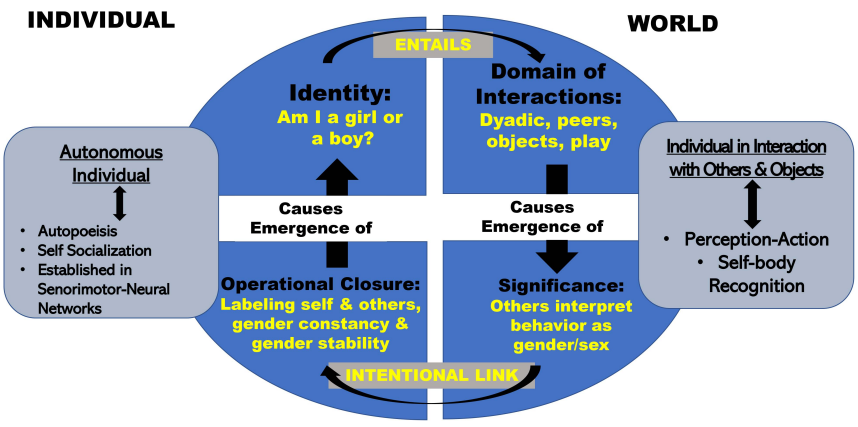

FIGURE 2 | Model of embodied development of gender/sex.

identity as both a property of the individual body/mind *and* a collective property involving interactions with others and with objects in the world. While identity may appear to be a "thing," it is actually a stable set of processes. Its development and continued maintenance and shaping depends on underlying activities that are both autonomous and intersubjective. Consider, for example, the common view of "properly" gender-identified boys and girls. The stereotypical boy runs around shooting a pretend gun and engages socially by chasing and running. The stereotypical girl plays quietly and engages in face-to-face social activities. Children in these idealized categories also prefer different clothes (Maccoby, 1998). Through these physical and interactive presentations, that vary continuously rather than in the stereotypical binary fashion so often presented, they come to understand themselves as a boy or a girl. They reinforce a blooming sense of identity by the very activities and codes of dress and conduct that led them to self-label in the first place. [On gender as process in adults see West and Zimmerman (1987), West and Fenstermaker (1995)].

During Phases 1 and 2 an infant's gender/sex-related neuromuscular and sensorimotor repertoires narrow, focus, and link to gender/sex in the world. In Phase 1, daily, moment-to-moment dyadic interactions are the crucial intermediaries connecting developing neural networks to "gender-in-the-world." As Phase 2 blends into Phase 3, the neural networks that mediate "gender-in-the-world" reverberate as gender/sex identity in the toddler's individual mind/body. This model is compatible with the idea that gender/sex expression and identity are interlaced continua. Through a variety of institutions, we usually force gender/sex identity and expression into a social and structural binary. For example, we only offer two possibilities on a birth certificate, two types of bathrooms, and until recently, children had only two identity options–boy or girl. To fit a continuum into a binary structure, researchers produced the concepts "gender non-conforming" or "gender variant." In contrast, I hypothesize that the range of individual infant, parent, and infant-parent dyad differences in motor (and probably other) behaviors shapes a range of gender/sex embodiment. Such shaping ultimately feeds into the stream of information out of which identity itself coalesces. If this is so, the behaviors currently labeled and measured as "gender non-conforming, gender variant, gender atypical or gender incongruent"–all phrases widely used in the psychological research literature to describe non-binary presenting children- simply fall among a number of possible gender/sex identities (Zucker and Wood, 2011; Drescher et al., 2016).

THE CHALLENGES: SYNTHESIZING THEORIES AND INVESTIGATORY APPROACHES TO EXPLICATING GENDER/SEX IDENTITY DEVELOPMENT

The offered dynamic systems theory of gender/sex development draws on findings from a range of disciplines These disciplines focus on levels of organization ranging from the cellular to the socio-cultural. This brings us to a remaining set of questions–how can we elaborate and specify this dynamic developmental account and accumulate empirical data to elaborate the details while repeatedly and bidirectionally crossing boundaries of scale? How can we figure out which bits are supported by new data and improved theory and which will turn out to be wrong, and how can we project the relationships between levels of organization of changes that happen within any one level?

Big Theory From Other Fields

Theoretical biologists and those who are trying to make sense of newly available large data sets are currently thinking and writing about how to traverse levels of organization. In this section I describe some of this work and point out ways in which it might translate to studying the dynamics of gender/sex development.

Rather than searching for causal links between evolution and development–events which happen on very different timescales-, Fields and Levin turned to "the language of communication, inference and information processing" (abstract) (Fields and Levin, 2020). Fields and Levin wrote that "The representation of organisms as active agents embedded in an interaction with active environments requires a reconceptualization of inheritance as the transfer across time not of a genome or other isolated memory-bearing structure but of . . .a living cell in continuous interaction with the environment" (pp. 4–5). In the following sentences I apply the structure of their argument to gender/sex development: In Phase 1 an infant is an active agent embedded in continuous interactions with active environments. These include the physical environment, the dyadic interactions with a caregiver and others, and the cultural environment within which the caregiver and others make behavioral choices. The infant encodes memories of repeated sensory events in its body- in the neuro-motor and autonomic nervous systems. These memories are comprised of continuously firing individual cells and collective neural activity rather than genes or genetic causes. During Phase 2, cellular- and organ-level memories begin to translate into cognitively accessible memories and emerge during Phase 3 as behaviors and subjectivity. During Phase 3 subjectivity stabilizes but, quoting Fields and Levin, it is not an "isolated memory bearing structure." Nor is identity located somewhere specific. Rather it is the collective property of all the events depicted in **Figure 1**. One implication of this approach for neuroimaging studies might be that researchers look for neural network activity under circumstances designed to challenge or modulate felt identity.

I conceptualize identity as a process rather than a thing. A process theory posits that identity self-organizes rather than being built according to a genetic blueprint. Nor is identity a fixed trait. Once stabilized it remains a dynamic entity, held more or less constant by a continuous back and forth between supporting experience and embodied responses. The fact that external experience and social context sustains and shapes identity means that it is fundamentally intersubjective rather than individual and autonomous.

In treating gender/sex as a self-organizing system, I draw from a large biological literature on self-organization (Barabási and Albert, 1999; Camazine et al., 2001). The recent work of Yufik and Friston (2016) which explores cognitive understanding as

an emergent property is of particular interest. They distinguish simple recognition (in my theory, for example, an infant's ability to recognize gender/sex in voices or faces) from abilities that demand what they call a "generative model." Yufik and Friston explain that a generative model of a circle (for example) entails not only the ability to visually recognize a circle, but also to imagine or perform manual circular manipulations, to walk in a circle), etc. "These abilities," they write, "require a generative model. . . distinct from simply recognizing objects . . .." In short, understanding is quintessentially enactive and "embodied," requiring one to actively engage with the causes of sensations." (pp. 8–9) (I think that by age 3 most children have developed generative models of gender/sex). Earlier in this article, I discussed the idea of statistical chunks linking multimodal experiences as they relate first to the recognition and then to the understanding of gender/sex. Here, I raise the question of whether such chunks might be what Yufik and Friston call neuronal packets that form in associative networks and that maintain an internal integrity. To describe these they invoke the statistical concept of a Markov Blanket that links different chunks or nodes. Markov blankets stabilize the nodes they cover, provide them with a certain amount of statistical independence within a network, yet keep them connected to one another (Friston, 2011).

This may seem too abstract or even inappropriate for a discussion of gender/sex. Indeed, Friston's work contains complex mathematical treatments of the statistical dynamics of semi-independent nodes and Markov blankets, a statistical concept that can link levels of organization. These mathematical treatments are beyond the reach of most students of gender/sex (myself included). But Yufik and Friston are working on a theory of embodied understanding, which is how I am trying to describe gender/sex. I believe that in response to a complex variety of sensory experiences, gender/sex concretizes in the body, specifically within the sensorimotor and autonomic nervous systems, and in behavior. Statistical frequencies and variations of specific experiences produce expectations based on the probability of a particular set of events. And events at one level of organization (say groups of nerve cells firing together) connect to others at different levels of organization (say a toddler demanding to put on pants or a dress). An academic discipline can be thought of as devoted to studying sets of associative networks within a particular level. To do interdisciplinary studies of the sort demanded by a multi-level theory of gender/sex requires a concept such as a Markov blanket that does the dual labor of both separating and linking different levels of analysis.

Finally, in thinking about how to move from one biological or developmental level of organization to the next, Delafield-Butt and Trevarthen take a non-mathematical approach by examining the early sensorimotor bases of the development of intersubjective and independent narrative (Delafield-Butt and Gangopadhyay, 2013; Delafield-Butt and Trevarthen, 2015). Although their proposed developmental trajectory from intentional sensorimotor movements *in utero* to the complex symbolic play of a toddler is linear, one could apply such a narrative analysis to non-linear developmental patterns. One might, for example, think of gender/sex as transforming from a precognitive narrative based on shared tasks that in infancy concern simple interactions (verbal narrative provided by the caregiver, movement and motor intentionality provided by the infant) to complex play involving movement, and conscious symbolism in toddlerhood. Such conceptualization, using the timeline presented in **Figure 1**, might provide a basis for future investigations.

Some Interesting Methodology

Practically speaking, how can researchers capture, measure the frequencies and durations of individual and joint behaviors, and assess the importance for gender/sex development, of mundane events that happen repeatedly during the first year of life? And once having obtained such data, would it be possible to link it to the emergence of gender/sex subjectivity? To begin with (and quite obviously), I am proposing longitudinal studies that, ideally, must last for at least 3 years (from birth to the acquisition of a preliminary gender/sex identity). Even better would be to weave into the study design the ability to check in on study subjects during mid childhood, puberty and late adolescence. Studies of this length are rare, but possible (Merrick, 2013).

In her short film of bathing infants in three cultures, Margaret Mead pioneered the use of narrated episodic, *in situ* observational recording for the study of infant development (Mead, 1940). During the 1960's researchers attempted to quantify naturalistic in-home studies using a multiple input keyboard attached to a mechanical event recorder (Moss, 1967). The quantitative analysis of film-based videos and finally of digital recordings followed in subsequent decades. But quantifying visual records is extraordinarily time consuming, requiring researchers to limit the number of study subjects and/or at great expense, hire a large number of human data analysts. In the past couple of decades, however, automated data recording has become available.

The LENA system, for example, provides automatic language recording, monitoring and analysis that can be used to examine vocal interactions between care-givers and infants. In one study of 16 h long interactions, Johnson et al. reported that infants from birth through 7 months experienced more female than male adult speech. Adult women responded more often to infant vocalizations and infants responded more to adult female, compared to adult male speech (Johnson et al., 2014). In a tour de force of what they refer to as "dense data collection" Roy and colleagues documented language development by recording a complete record of sounds and words made by a single child during his first 3 years of life (Roy et al., 2015). They concluded that mere frequency of word repetition was less important for language learning than the location in which a word was spoken, as well as the time of day and the ways in which a particular word was embedded in the context of everyday speech. As fascinating as the Roy et al. study is [see also (Roy et al., 2006)], their methods present difficulties for widespread adoption. One compromise between a totally and intrusively wired home environment and artificially structured laboratory experiments is to study free play in a home-like environment that has multiple camera angles and sensors distributed in the room. Yu (2020) created such an environment in order to study coordinated parent-infant social interactions, and a variety of multimodal parental effects on infant visual attention. With

some thought, a multiply wired home-like environment that can record interactions from several points of view, could be adapted to the study of gender/sex, provided it was coupled with an assessment of the actual home environment (home visits to assess physical and toy environment, questionnaires designed to assess gender/sex beliefs of caregivers, etc.).

Automated data collection and analysis has become part of the next wave of infant study. de Barbaro proposes best practices for the use of wearable sensors to record motion, autonomic function and vocalization within what she calls the ecology of daily activity (de Barbaro et al., 2013b; de Barbaro, 2019). She also advocates for the study of unstructured home-based activities. de Barbaro notes that many aspects of natural activity are not present in carefully structured laboratory activities which are, in the first place, designed to limit the number of study variables. Wearable sensors permit the collection of large volumes of data, recording activity over varying timescales, thus allowing the potential analysis of phenomena that develop over hours, days, weeks, and months. Although de Barbaro and colleagues have not applied their approach to the study of gender/sex, there is no reason to think that gender/sex differs fundamentally from other developmental phenomena; I argue that this extensive new methodology be applied to the study of gender/sex development rather than continuing to study children in over-simplified settings with a stripped down number of study variables.

de Barbaro discusses the several methodological challenges to embracing these new technologies and to reopening the study of development to long-term open-field conditions. These, of course, require attention, but in this essay I want to emphasize the direction the field ought to take rather than offer reasons for why a new path cannot be developed. One last note about technology. Just as de Barbaro champions wearable sensors that can detect movement, emotion and interpersonal interactions, the work of Kuhl and her colleagues demonstrates that wearable sensors can reach "down" into the brain for the analysis of brain activity correlates of specific behaviors (Kuhl et al., 2001; Kuhl, 2004, 2010; Kuhl and Rivera-Gaxiola, 2008). Thus, interdisciplinary study designs that reach "down" into the body but also out into the surrounding world are within reach.

The turn to dense, multimodal, and longitudinal data collection also requires new types of statistical analysis. de Barbaro reviews a number of these, including visualization techniques such as state-space grids (Hollenstein, 2007, 2013), and statistical modeling of use for analyzing dense, repeated measures data. **Figure 3** illustrates, for the purpose of example, some results from Fausto-Sterling et al. who used a form of longitudinal analysis developed by Singer (Singer and Willett, 2003; Fausto-Sterling et al., 2020). The graph illustrates gender/sex differences over time in maternal shifting of the infant from one location to another (Fausto-Sterling et al., 2020). This graphical presentation has the advantage of showing group differences (illustrated in the bottom panel of **Figure 3**) while also allowing the visualization of within-group individual differences. We can also visualize the statistical distribution of multiple behaviors using three dimensional visualizations. **Figure 4** is a three dimensional state-space graph of three maternal behaviors, affectionate touch, assisted locomotion and maternal vocalization in mother-son and mother-daughter dyads when the infants were 3 to 4 months of age. This representation allows the viewer to look at individual data points while also using the mesh blanket to conceptualize the idea of 3-dimensional state spaces for combinations of maternal behavior.

In a different approach, Eason and colleagues explored relationships in mother/infant interactions using vector autoregression analysis. This method promises an approach for testing gender/sex salience in multimodal, bidirectional effects in a dense, multimodal data set (Eason et al., 2020). Finally, both biologists and cognitive scientists are exploring the use of Bayesian statistics in the longitudinal study of development. Kuchling et al. developed Bayesian models to explore how small groups of cells assess their individual and collective states and predict their own forward-looking genetic and physiological activities based on their reading of the environment created by other small groups of surrounding cells. The developmental goal is to cooperate in achieving complex pattern formation and morphogenesis. In this model, cells use Bayesian inference, which is a statistical process in which cells update their prior physiological state based on contemporary sensing of their current environment (Kuchling et al., 2020). Directly germane to cognitive development, Gopnik champions the use of Bayesian methods to explore how children derive and build cognitive theories, and it should be worthwhile to apply such methods to the development of children's theories about gender/sex (Gopnik, 2010; Gopnik and Bonawitz, 2015).

Visualization can help us understand developmental complexity, including transitions along widely varying time scales and between levels of organization that range from cells to behaviors to subjective psychology. By doing a deep dive into C.H. Waddington's famous drawing of epigenetic landscapes, feminist science studies scholar Susan Squier explored drawing as metaphor. Waddington's illustrations, she argued, entail "productive engagements with the unknown" (p. 17) (Squier, 2017). Baedke reviewed some of the ways in which Waddington's drawings contributed to the development of new knowledge in fields of study ranging from applied mathematics to developmental psychology (Baedke, 2013), while Flower explores the use of visualization to understand the dense data produced by studies that produce individual molecular profiles for thousands of single cells (Flower, 2020). As an example, **Figure 5** uses a modification of one of Waddington's drawings to visualize events described in **Figure 1**. In the original, balls (i.e., organisms) rolled down the landscape reaching final phenotypes. Waddington imagined genes as fixed guy-wires that shaped the developmental landscape by pulling from underneath. The redrawing imagines the pulls as swinging weights representing landscape-shaping inputs ranging from physiology to culture. This visualization emphasizes dynamic movement, although it is still not quite right because the possible effects of the developing organism on the weights themselves as well as development over the life cycle are not properly illustrated.

Interdisciplinary Collaboration

How can a researcher trained primarily in a particular discipline possibly accomplish such long term and multidisciplinary tasks?

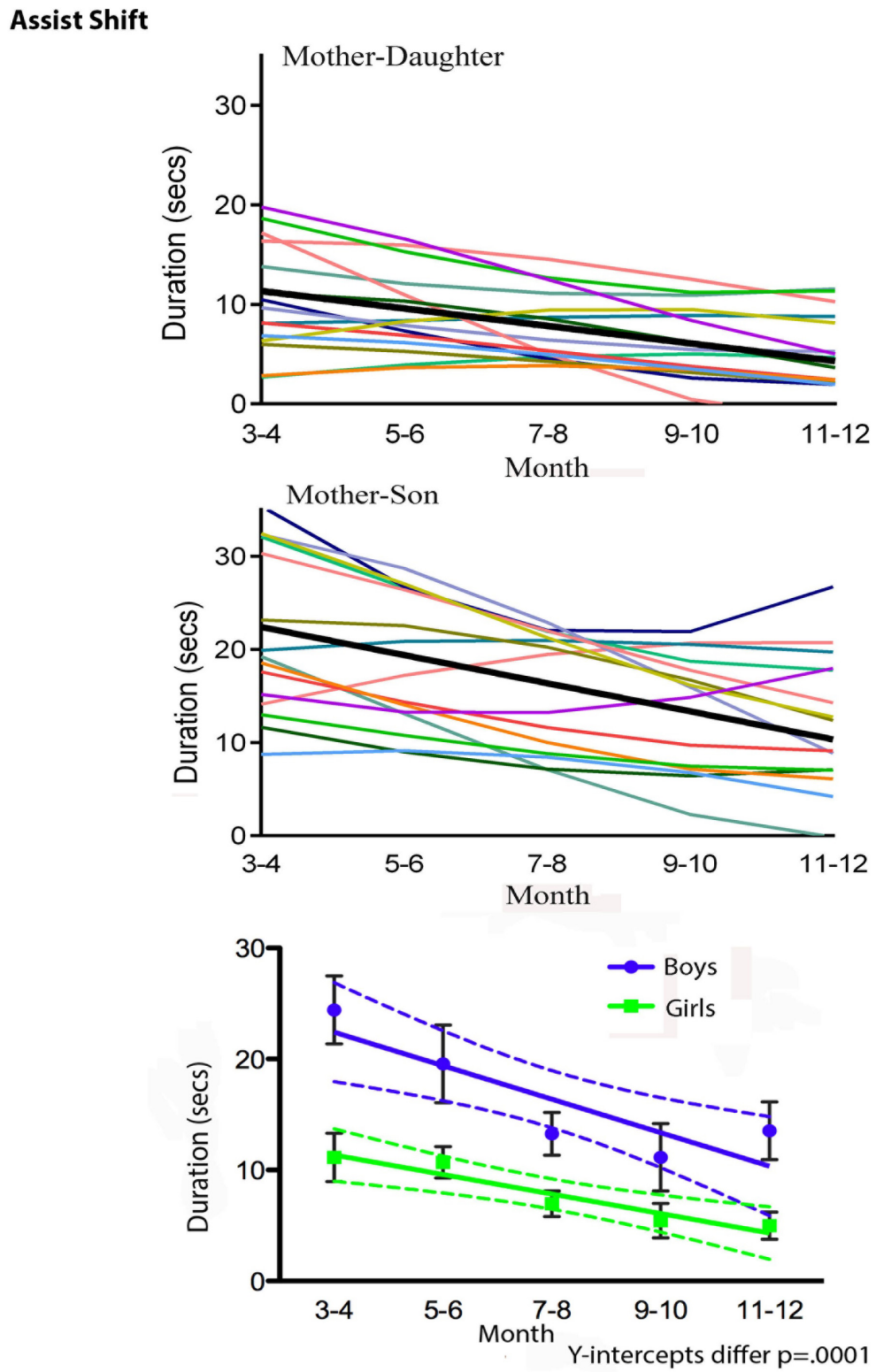

FIGURE 3 | Duration of Assist Shift in 2-month groups from 3 to 12 months. Top panel shows individual dyads with girls (thin colored lines) and a regression line for dyads with girls (thicker black line). Middle panel shows individual dyads with boys (thin colored lines) and a regression line for dyads with boys (thicker black line). The bottom panel shows group regression lines and standard deviations (square symbol, green line = mother-daughter dyads; round symbol-blue line = mother-son dyads).

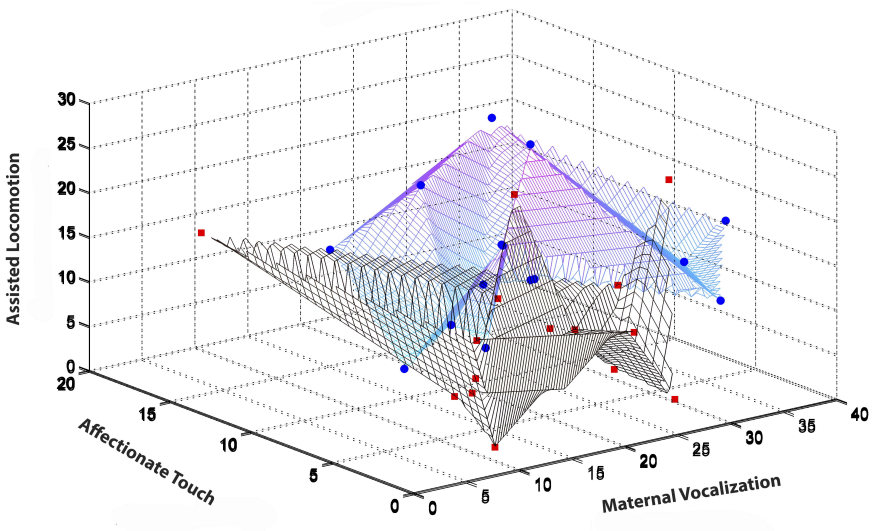

FIGURE 4 | Illustrates the 3D state space occupied at 3–4 months of infant age for the maternal behaviors of assisted locomotion (*Y* axis), affectionate touch (*X* axis), and maternal vocalization (*Z*-axis). Two types of graphs–a mesh and a scatterplot are overlaid. The blue circles (mother-son) and red squares (mother-daughter) represent individual mother-infant dyads. The black-lined mesh represents the state-space occupied by mother-daughter dyads, while the blue-lined mesh represents the state-space occupied by mother-son dyads. Color variation (from blue to purple) results from mesh density.

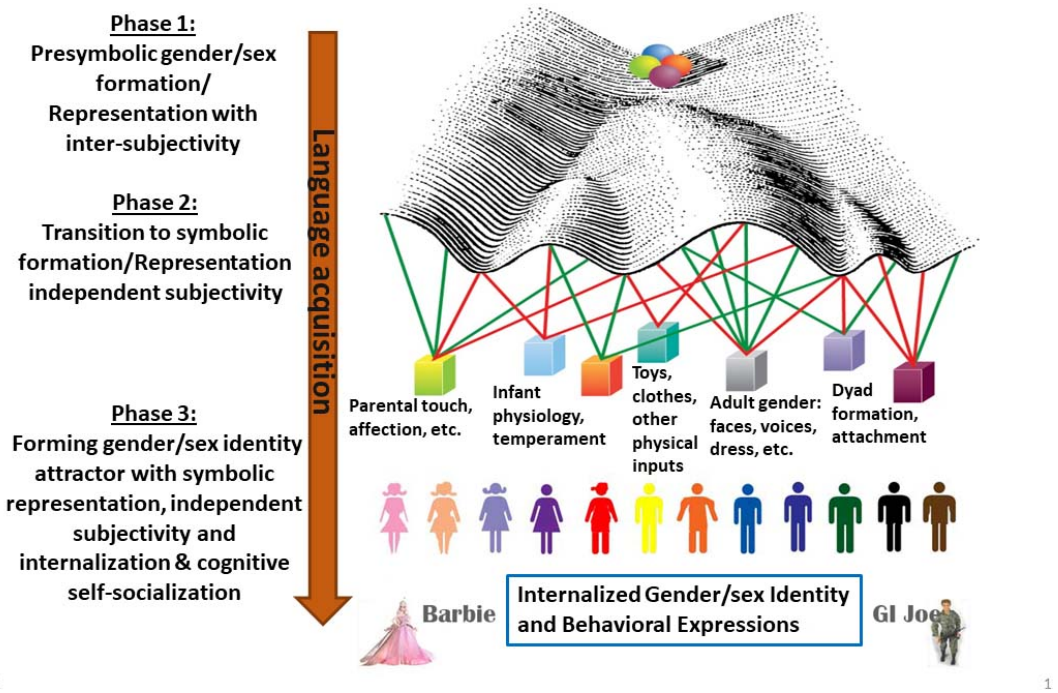

FIGURE 5 | The left side of the diagram reiterates the phased development of gender/sex from intersubjective to subjective. The right side visualizes the process as a modification of a Waddington-style genes and landscape drawing. The drawing represents Waddington's guy-wires as swinging weights representing landscape-shaping inputs ranging from physiology to culture, and producing a continuum of gender/sex. One might imagine that Phase 1 correlates with the initial start of the balls rolling downhill and probably includes the initial bifurcation in the landscape. Phase 2 might be seen as starting with the secondary bifurcations (drawing by the author).

The answer: through collaborative consortia such as the Many Baby Project (MBP) or the Baby Connectome Project (Bergmann et al., 2020; Elison, 2020). The Many Baby Project provides one possible starting model for a collaborative, interdisciplinary research consortium on gender/sex (Many Babies, 2021). Begun in 2016 with the express purpose of addressing the replication

crisis in psychology, participants identified as a central aim to better understand why different labs that use similar methods get different experimental results. To further this aim MBP collaborators agreed to replicate a small number of findings on infant development that, based on metanalysis, seemed "true" even though individual reports did not always replicate the finding (Frank et al., 2017). They hoped also to increase the non-WEIRDness of their study sample, lessen the burden of large-scale data collection for any one lab, standardize study methods to make data more directly comparable from one site to the next, and use an open science framework to make raw data available for secondary analysis. Their operating principles included collective governance, inclusivity and diversity, and ethical research. The MBP participants provide a rich record of their process and online tools that could be adapted for the study of gender/sex in infancy (Bergmann et al., 2019).

However exciting, the MBP project does not venture into an interdisciplinary framework that traverses levels of biopsychological organization ranging from cellular function and physiology, to brain organization and function, to individual and dyadic behavior patterns and subjectivity. To accomplish such multilevel analyses participants must learn to have interdisciplinary conversations. The goal is to figure out how to draw conclusions that translate across levels of organismic organization (and disciplinary boundaries). Like the theory itself, the collaboration must focus on emergent rather than additive developmental models.

A group consisting of individuals from disciplinary backgrounds ranging from feminist philosophy of science, to experimental neuroimaging modeled such an effort by having an interdisciplinary conversation about strongly believed-in findings of gender/sex differences in spatial abilities in adults (Bentley et al., 2019a,b). Initially they had hoped to agree on an experimental design that studied gender/sex and spatial abilities across levels of organization from the hormonal to the social. They began, as any inter-disciplinary conversation must, by making explicit their own causal models and clarifying their varied uses of the sex and gender terms. As they worked toward a common language for underlying theories of experimentation and of gender/sex, they diagrammed variables of interest and illustrated what they called their entanglements [see also (Fausto-Sterling, 2000), pp. 141–143]. As their discussion proceeded, Bentley et al. (2019b) realized that a single protocol could not accommodate all of the issues they had raised, and so they chose to "showcase . . .a negotiation process–an aspect of collaborative research that usually remains a non-public affair. . ." p. 2/20 (Bentley et al., 2019b). I cite this effort not because it succeeded in its initial goal, but because it was a first attempt. We need more conversations of this sort aimed at devising empirical and theoretical investigations into gender/sex identity formation.

CHEERLEADING AND SUMMARY

We can take advantage of new developments in the brain sciences and in the study of infant development to investigate gender/sex as it emerges in toddlers. The use of wearables that record neural activity and physiological change, and of automated recording of individual and dyadic behaviors, and the development of theory aimed at understanding moments of transition and the establishment of stability provide the potential to achieve new understandings of the early development of gender/sex. As complex as such a project might be, it seems worth it for several reasons. First, it would be nice to do better science, to move in a positive way toward understanding gender/sex variability. Second, getting the science right (or at least better) can help with the development of sensible health and social policy having to do with the development of job opportunities and better health care for the full range of gender/sexed humans (Şahin and Soylu Yalcinkaya, 2020).

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Brown University Institutional Review Board. A copy of the original consent form may be obtained from the author.

AUTHOR CONTRIBUTIONS

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

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Over the past decade a number of individuals and list-serve-style groups have supported my efforts to break out of the rather staid approaches found in the field of gender and development located within the discipline of developmental psychology. These friends and colleagues (they know who they are) have encouraged me to keep trying to get my ideas published within conventional child development journals, and when the doors to these journals remained shut, the same supporters acknowledged that the main field is closed to outsiders. That acknowledgment, as I have battled accusations of scholarly and writerly inadequacies, has given me the strength to try again. I hope this current effort warrants their continued support. I also thank the reviewers of this manuscript for their thoughtful and constructive comments.

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"Mombrain and Sticky DNA": The Impacts of Neurobiological and Epigenetic Framings of Motherhood on Women's Subjectivities

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The fields of epigenetics and neuroscience have come to occupy a significant place in individual and public life in biomedicalized societies. Social scientists have argued that the primacy and popularization of the "neuro" has begun to shape how patients and other lay people experience themselves and their lifeworlds in increasingly neurological and genetic terms. Pregnant women and new mothers have become an important new target for cutting edge neuroscientific and epigenetic research, with the Internet constituting a highly active space for engagement with knowledge translations. In this paper, we analyze the reception by women in North America of translations of nascent epigenetic and neuroscientific research. We conducted three focus groups with pregnant women and new mothers. The study was informed by a prior scoping investigation of online content. Our focus group findings record how engagement with translations of epigenetic and neuroscientific research impact women's perinatal experience, wellbeing, and self-construal. Three themes emerged in our analysis: (1) A kind of brain; (2) The looping effects of biomedical narratives; (3) Imprints of past experience and the management of the future. This data reveals how mothers engage with the neurobiological style-of-thought increasingly characteristic of public health and popular science messaging around pregnancy and motherhood. Through the molecularization of pregnancy and child development, a typical passage of life becomes saturated with "susceptibility," "risk," and the imperative to preemptively make "healthy' choices." This, in turn, redefines and shapes the experience of what it is to be a "good," "healthy," or "responsible" mother/to-be.

Keywords: neuroscience, epigenetics, knowledge translation, media, pregnancy, motherhood, perinatal period, mental health

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INTRODUCTION

In this paper, we set out to analyze women's engagement with nascent epigenetic and neuroscientific bodies of research in North America. This is part of our broader interest about the extent to which, and ways in which, new knowledge related to the brain and genetics is shaping our subjectivities, and impacting on decision-making, treatment, and recovery in clinical contexts. We bring interdisciplinary perspectives from psychiatry, cognitive neuroscience, and the social

studies of neuroscience to bear on the translational impacts of the neurosciences and epigenetics in new and expectant mothers in Quebec, Canada, as a case population. Our premise is that given the cultural authority of neuroscience, the application of findings to patients, practitioners, and lay users warrants careful analysis. This is particularly timely in view of important theoretical, methodological, and interpretive uncertainties in experimental methods and in the translation of neuroscience to societal applications, as the field moves to incorporate aspects of social and cultural context. While social theorists and historians have expressed significant concern about potentially reductive, individualistic, or pathologizing impacts on users, some have also overstated the transformative potential (Martin, 2010; Choudhury et al., 2012; Pickersgill, 2013). We explicitly seek to examine how consumers of these research translations understand, interpret, and are affected by epigenetic and neuroscientific information, rather than a focused discourse analysis of the translations themselves. This study provides an opportunity to bring nuance to this analysis through an understudied population of active consumers of this knowledge, and to examine how interpretations of brain science frame narratives about women's bodies and experience.

The Medicalization of Pregnancy

Bodies as objects to be appraised, polished, promoted, protected, kept pristine as commodities, and assets have throughout history forced women to regard their own with suspicion. Early feminist writings push against any deterministic association between bodily characteristics, mind and its faculties, and social roles (Wollstonecraft, 1792 [1988]; Mill and Taylor, 1970). The female body has a history of social regulation whether as an object of desire, site of family control, or symbol of fertility, scrutinized, intervened, and controlled through formal and informal structures, narratives and images. Here, we are concerned with the role of biomedical science in the understanding and experience of the perinatal period among contemporary mothers and expectant mothers in biomedicalized societies. While biomedical science has a prominent role in lay approaches to motherhood, its role is not new and has its own history of management of women of reproductive age, during pregnancy and early motherhood. At the turn of the twentieth century, women in Western Europe and North America had minimal engagement with the medical profession over the course of their pregnancies (Al-Gailani and Davis, 2014). Social control of the female body was monitored through other cultural and religious institutions and channels. Within 100 years, the purview of science and medicine in human reproduction saw a striking evolution: the hospitalization of childbirth, The contraceptive Pill, prenatal vitamins, obstetric ultrasound, etc. (Al-Gailani and Davis, 2014). Some scholars argue that the transformation of pregnancy "from a natural event into a medical problem" (Seccombe, 1990, p. 181) has led to heightened scrutiny of "subjectively healthy populations" (Al-Gailani, 2014) and established new classes of patients and categories of disease (Al-Gailani, 2014). Though a deep treatment of this subject is beyond the scope of this manuscript, the historicization of the extension of biomedical authority, practice, and dominion into domains of women's preconception health and pregnancies contextualizes the current popularization and mobilization of contemporary biomedical approaches to optimizing fertility, infant health, and managing interventions.

Within the last few decades the field of epigenetics has shed new light on the mechanisms by which maternal environment influences outcomes in child development, and neuroscience findings indicate that experiences during "[neurobiologically] critical periods result in irreversible changes in brain function" (Nelson and Gabard-Durnam, 2020). The particular potency and reach of these new ways of thinking about pregnancy and early motherhood rest on a complex web of relations between the laboratory, journalism, policy makers, the vested interests of industry, and the affects, hopes, expectations, and social contexts of women of reproductive age. The specific forms and platforms of the translation of this research prevalent in the Euro-American context, the prevailing cultural rhetorics in circulation, the particular parties, and processes—all of which shape its bearing on women's perinatal experience—are unique to this moment. Yet, while the current actors and dynamics are specific to today, this phenomenon can be seen as part of a trend: a historical process of the increasing sphere of influence of biomedical science on life and self and the age-old utopic project of human improvement through scientific discovery and technological progress.

Risk and the Making of New Norms

The study of the development of perinatal interventions demonstrates how both the identification of risk and the construal of risk are created in biomedicine and converge with social forces to make possible new ways of managing the (pre-)pregnant body. The prominence of medical regimes from diagnostic services to technological monitoring and intervention in the perinatal period has led many researchers to analyse the increase of "scientific motherhood" (Apple, 1995) and the production of new norms through biomedicine. For example, the mobilization of research linking folic acid to normal fetal development changed the relationship between the State, other actors, and pregnant women based on a moral imperative to mitigate risk and maximize optimization. The history of the now routine use of folate in pregnancy reveals how the emergence of new technologies in biomedicine afforded new ways of interpreting and delineating a "healthy" pregnancy (Al-Gailani, 2014). In the 1960s, for example, the development of microbiological assays of blood serum and its application to practice enabled the clinical study of megaloblastic anemias, which identified a "previously unknown problem": without any clinical indications, a majority of women were mildly folate-deficient (Al-Gailani, 2014). Folic acid supplementation is now an imperative in biomedicalized societies—and globally exported as a biomedical norm—when trying to conceive, scaffolded by the interplay between scientific discovery, evolving medical practice, industry uptake, social and political interest, and popular messaging. In this way motherhood exemplifies a new and increasingly widespread way of thinking about health that combines a probabilistic logic of risk with the imperative to manage the future health of the body at the molecular level (Rose,

2009) through interventions in the present. The brain and genes of the mother and baby have become a contemporary site for this to play out.

Plasticity, Intergenerational Transmission, and the Optimization of the Unborn Infant

In 2020, scientific research in the field of epigenetics exposes the phenomenon of intergenerational transmission of experience, further expanding the conception of the variables and necessary (windows of) interventions that constitute and engender a healthy pregnancy and optimal infant outcomes. These research bodies explore distinct temporal windows: epigenetic effects related to events or environments that precede pregnancy, occur during pregnancy, or during the postpartum period, where the plastic infant brain may also be affected by non-epigenetic means during critical periods of development. The plasticity of the maternal brain has also been the subject of inquiry both during and post pregnancy. Today, it is as if women are "eternally pre-pregnant" (Meloni, 2016, p. 217). New interpretations of epigenetics research not only have implications for risk management for the pregnant mother and unborn infant but also for the *potential* health of future generations. The transmission of traits across generation has long been conceived as the inheritance of genomic information, but recent research suggests that lived experience may be inherited through epigenetic mechanisms. Epigenetic research in animals—with a smaller body of literature reporting human studies—has suggested that variables ranging from trauma (Yehuda et al., 2014) and maternal mental health (Meaney and Szyf, 2005; DeSocio, 2019) to environmental exposures (Takiguchi et al., 2003), metabolism, diet, and other lifestyle conditions (Parle-McDermott and Ozaki, 2011), to postnatal maternal care (Bagot et al., 2012) have a bearing on cognition of the child. New neuroscience and epigenetics have been thus implicated not only in the management of preconception and pregnancy health of the mother but also in the optimization of the unborn infant. This is premised on pervasive messaging about neuroplasticity, or the impressionability of the developing brain. Specifically, cognitive neuroscience research on early childhood brain development points to critical windows of infant brain plasticity: the particular structural malleability and concurrent sensitivity to environmental stimuli confer particular potential for enhancement or vulnerability to affronts (Hess, 1976; Greenough et al., 1987; Black et al., 1998; Knudsen, 2004). It also points to changes in the maternal brain brought about by pregnancy and birth (Hoekzema et al., 2017; Barba-Müller et al., 2019) that may "not merely [be] adaptive, [but] likely confer a vulnerability for the development of mental disorders" (Barba-Müller et al., 2019). As Wastell and White (2017) write, "If brains can be damaged or boosted, should we not be boosting them or preventing the damage?" As scholars have already documented, the materiality of the plastic brain bears strongly on the popular imagination: the possibilities to influence developmental trajectories, reverse historical processes, or enhance/protect mental health by working on tangible cellular processes, that are visible at a macro-level through mesmerizing neuroimagery, is widely incorporated into clinical settings, public health messaging and popular science (Choudhury et al., 2012; Pitts-Taylor, 2016; Rees, 2016). Epigenetic science has already shaped policy and can be found referenced across a wide variety of cultural locales. Innovations in epigenetics and neuroplasticity related to mother-infant interactions have been of enormous interest to the media and public, with the Internet constituting a highly active space for engagement and cultural prosumption (Toffler, 1980) of translations of said research.

Translational Impacts of Epigenetics and Neuroscience of Pregnancy and Motherhood

Popular media coverage plays a powerful role in the translation, reception, conciliation, and comprehension of science in the public sphere. "Traditional" media forms—including magazines, newspapers, radio, and television—that controlled a unidirectional flow of information to the public sector now exist in a broader ecosystem of platforms that support two-directional sharing of rhetoric, ideas, and information where audiences not only consume but also construct media content (O'Connor and Joffe, 2013, 2014) including for-profit company blogs, Instagram, YouTube, etc. A Google search of "epigenetics" surfaces a top hit—whatisepigenetics.com[1]—an alleged educational site by epigenetic biotechnology company EpiGentek, to "bring the science of epigenetics to the forefront of everyday life." It contains over two dozen blog posts and claims to "translate" epigenetic research related to pregnancy to the lay public.

In 2016, Nature Neuroscience published, *"Pregnancy leads to long-lasting changes in human brain structure" (2017*) reporting that pregnancy was associated with reductions in gray matter volume. Popular UK online platform, motherandbaby.co.uk, centered on pregnancy and motherhood recommends "Top brain training apps to combat baby brain" and #MomBrain podcast launched in 2018 (Walling, 2018) with 119 episodes available through Apple Podcasts, Spotify, and other players. Headlines from *Science Magazine,* "Pregnancy resculpts women's brains for at least 2 years" (Wadman, 2016), *Parents* "Mommy Brain: Yes, It's a Thing" (Lucia, 2018), *Scientific American,* "Does "Pregnancy Brain" Exist?" (Does "Pregnancy Brain" Exist?, 2016), *Independent's* "Pregnancy really does cause 'baby brain', new research finds" (Young, 2018), and Instagram hashtags like #mombrain (appended to 97.4k posts), #pregnancybrain (31.3k posts), #babybrain (48.6k posts), #ppd (287k posts), reflect the exceptional public interest in brain changes over the course of the prenatal and postpartum period, the myriad actors and spaces involved in the prosumption of these bio-cultural narratives, and the influence of the biomedical in the realm of the subjective: experiences of pregnancy and motherhood framed as expressions of impacting and shaping "brainhood" (Vidal, 2009), the neurobiological recasting of personhood.

Over the course of a few decades, the neurosciences have come to occupy a significant place in individual and public

[1]Parenting, Pregnancy, and Epigenetics. *What is Epigenetics?* Available online at: http://www.whatisepigenetics.com/topic/parenting-pregnancy-epigenetics/ (accessed December 11, 2020).

life. Scholarly attention to this phenomenon has highlighted a contemporary fetishizing of brain images (Vidal and Ortega, 2017), the popular fixation on the brain, the blossoming of neuro-prefixes—such as neuro-education, neuro-psychoanalysis, neuro-aethetics—and increasingly common prioritization of the neuroscientific lens on phenomena once the purview of other disciplines of thought (Vidal, 2009; Rose and Abi-Rached, 2013). The primacy of the "neuro" in culture has led to assertions that we experience ourselves and lifeworlds in increasingly neurological as opposed to psychological or internal impressions (Ortega and Vidal, 2007): it is argued that we are more and more "cerebral subjects" (Ortega and Vidal, 2007) or "neurochemical selves" (Rose, 2003).

The dynamic and interactionist nature of the burgeoning new media landscape warrants increased exploration of public engagement with science across media platforms and increased scrutiny of the potentially unforeseen ethical and psychological implications of dialogue in these spheres. Further empirical analysis can also help to understand the cultural appeal of neuroscience and epigenetics.

The translations of biomedical information about pregnancy and motherhood in brain-centric idioms like "mombrain," "pregnancy brain," or "postnatal depletion" to narratives around maternal epigenetics—the impact of an organic Atlantic salmon roe diet (foundmyfitness, 2017) and the cigarettes one's partner smoked as a teenager (Kirkpatrick, 2016) on their child's cognition—have implications for the expectations, reference points, and self-imposed regimens for women during their pregnancies. Little to date, is known about how findings in these particular subject areas are interpreted by various publics. Empirical research has corroborated the distortions that occur when neuroscientific information permeates the public sphere (O'Connor et al., 2012) and critical neuroscience research has documented how health recommendations acquire scientific authority through references to the brain (Choudhury and Slaby, 2012). Interpretations are influential factors in an individual's psychological and physiological reality. So far, there is a gap in the literature assessing how the mobilization of brain and genetic data to frame motherhood is affecting women's choices and self-understanding.

In this study, we set out to address this gap by exploring how translations of neuroscientific and epigenetic information in the form of "epigenetic imaginaries," (Jasanoff and Kim, 2009; Meloni and Testa, 2014), impact the experiences, attitudes, and mental states of women during the perinatal period. In this paper, we present results from focus group conversations with expectant and new mothers. Our focus group interview guide was informed by a prior familiarization with a range of diverse actors and outlets where epigenetic and neuroscientific translations are taking shape.

Objectives

Based on our analysis of existing literature on the role of genetics and the "neuro" in contemporary biomedicalized culture, we were led by the broad question of how the primacy of the "neuro" in contemporary North American society affects women's subjective experience and understanding of their pregnancies and motherhood. To explore this, we approached the online material and focus groups led by questions such as: What does it feel like to engage with translations of epigenetic research? Is the take-away message from epigenetic research one of fixity or flexibility, control or lack thereof? How are women responding to or making sense of these translations? How do they relate to and feel about the cultural belief that pregnancy and motherhood changes the brain? To what extent is this brain-based explanation a liberating development or grounds for stigmatization? To what degree does "pregnancy brain" reframe expectations of competence or capability during and after pregnancy? What might the increasing prevalence and popularization of brain-based explanations indicate about the role of neuroscientific "proof" in the legitimization of women's experiences during the pre/postpartum period? Our overarching goal is to examine the functions of epigenetic and neuroscientific vocabularies and metaphors among a population who are frequently exposed to these ideas. This research was conducted during the COVID-19 pandemic. The specific context of the pandemic likely adds layers of complexity that may have intensified attention, shape awareness and affective experience of translations of these bodies of knowledge.

MATERIALS AND METHODS

We conducted three focus groups with pregnant women and new mothers. The aims of the focus group were to examine (1) how knowledge translation of epigenetics and neuroscience impacts women's decision-making and experience of the perinatal period; (2) the impact of this engagement on women's wellbeing and self-image.

The focus groups' semi-structured interview guide was developed against the backdrop of insights gained from an immersive background scoping study of online sources of biomedical translations that provided a foundational overview of where and how these bodies of knowledge emerge in public discourse. Given that the Internet-mediated world is a space of fervent exchange and debate around pregnancy, birth, and the female body for contemporary women, we sought to discern predominant narratives and dynamics online. **Box 1** offers examples of online content that provide a window into the material that women can encounter online and provide added context for the participants' narratives that specifically mention Internet content.

Ethics approval was obtained and sanctioned by the Institutional Review Board of McGill University (IRB Study Number A10-B60-19B).

Focus Groups

Recruitment

Participants were recruited through two local organizations in Montréal providing perinatal services and by posting the opportunity to a local Google Group for parents. Recruitment occurred between July and November 2020. The total number of study participants was reached through the processes of purposeful and snowball sampling. Recruitment sites were chosen to recruit as demographically diverse a sample as possible

BOX 1 | Examples of Neuroscientific and Epigenetic Translations Online

The following are four examples of online content related to epigenetic and neuroplasticity research that women may encounter. These examples do not represent the breadth and depth of digital translations of these bodies of research, but are illustrative nonetheless:

A) A post in November, 2020 by a public Instagram profile reads "I used to have functioning brain cells, but I traded them in for children," the text super-imposed on an illustrated image of a woman holding two children. The image's caption includes the following:

"I read something the other day where a mom warmed up a plate of food, walked into the living room, sat down and thought—I'm hungry I should make something to eat. I don't know how many times I've walked into a room to do something and then forgot as soon as I entered□♀□ Seriously anyone else feel this way?!?

#mombrain #itsarealthing #iusedtohaveagreatmemory #momoftwo #mombrainisreal #girlmom #boymom #lovemykids"

B) A VeryWellFamily.com 2020 article—reportedly written by healthcare professionals and fact-checked (Verywell Family, 2019)—on "Mommy Brain" begins with the following conceit:

"Do you ever walk into a room only to forget why you went in there? Have you ever been searching frantically for your cell phone or your keys, only to find that they are in your hand? Or maybe you call your dishwasher the washing machine or blank out on the names of your coworkers. If you are experiencing any of these things, it is likely that you have "mommy brain."

Even though "mommy brain" may sound like a fictional condition or a convenient excuse for forgetfulness, it is actually a true condition backed up by science. In fact, research shows that a mother's brain is impacted by having children, sometimes in long-lasting ways.

For instance, a study by the University of British Columbia demonstrated that motherhood has a permanent impact on your cognitive function.

Meanwhile, a study in Nature Neuroscience found that even two years after pregnancy, women had gray matter brain changes. These changes took place in regions involving social cognition or the ability to feel empathy for another person. In other words, some subtle aspects of memory are sacrificed to enhance other areas of cognition (Gordon, 2020)."

C) A YouTube video titled *"Epigenetics"* published on January 22, 2012 by the YouTube channel SciShow. At the time of writing this video was the number one search result for a search query of "epigenetics" on the YouTube search function—filtering by view count—with 2,299,856 views; SciShow had (6.53 M subscribers). The video length is 9 min and 29 s. The transcribed audio from minute 5:32–6:09 is as follows:

"And it just so happens that the more they study this, the more it looks like bad epigenetic information is being passed from generation to generation. And this is a whole new way to think about how we pass information between generations.

Your grandmother was making dietary decisions that affect you today. As we experience all these new strange epidemics—diabetes, autoimmune disorders, cancers—that weren't appearing in previous generations, it's starting to look like these may be caused by epigenetic information passed down from our parents.

I know! It's such an unbelievable buzzkill! There is no point in our lives when we can do anything without guilt anymore!"

At the time of writing, this video has 4,749 Comments. When sorted by "Top Comments," the text of the first two comments are:

1: "I actually think this is uplifting rather than depressing. If you choose to have offspring, you can make decisions now that give your descendants a potentially better life. Exercise regularly and eat right? Your kids might be more likely to do that, regardless of your original genetics."

2: "DAMNIT GRANDMA"

D) The first three paragraphs of a blog post published by whatisepigenetics.com titled, "5 Ways You Might Epigenetically Boost Your Child's Health Before Birth," published January 29, 2018.

"When the Twin Towers came down in 2001, it was one of the most shocking moments in human history. This brazen act of terror traumatized an entire population. For those who lost friends, family, and acquaintances in the tragedy, it was an enormous cause of stress, grief and general departure from a normal state of being.

Among the affected, many were pregnant women—some of whom developed PTSD after the incident. As reported in The Journal of Clinical Endocrinology and Metabolism, when these women gave birth, there were certain peculiar effects observed in the children. The children who had mothers with PTSD were born with lower levels of cortisol, whi-ch is known as the stress hormone. In addition, their responses to stress-inducing stimuli in their environment were dysfunctional.

Although none of these kids had witnessed the horror themselves, their biochemistry reacted as though they had. This wasn't some random coincidence. It was a demonstration of the power of epigenetics."

so that group composition reflected a range of vocations, socio-economic statuses, ethnicities, educational backgrounds, and ages. Women who had already given birth were required to have a child under the age of 5-years-old. Participants were informed of the study objectives, focus group process, and data protection prior to participation. Informed consent was secured in writing and participants indicated whether they preferred not to have their name associated with their comments. Women could choose to rescind their participation at any point without explanation. Three women initially signed up to participate but were unable to attend the focus group due to scheduling conflicts.

Focus Group Guidelines and Process

Three separate focus groups were held with a total of 17 participants: the first and second group comprised six women and the third group, five. Discussion was steered by a semi-structured interview guide developed by the research team. The interview questions were designed to stimulate discussion by providing a starting point for respondents to contribute further statements on the subject. Questions were not asked verbatim across groups nor was there a strict chronology in delivering specific questions across groups. The questions were posed so that the interviewer could probe particular subject areas that arose as thematically pertinent and direct the conversations to foster a degree of topical consistency across the three groups, as fitting. Participants discussed questions based on their own personal experiences and point of view.

The questions were divided into eight themes: information sources about pregnancy and birth; social media platforms; biomedicine; genetics/epigenetics and motherhood; neuroscience, the brain and motherhood; expectation; birth; motherhood and support systems.

Questions included (but were not limited to):

i Queries about general types of pregnancy and motherhood content that participants engaged with during the perinatal period and from where this information was sourced;

e.g., *"Where have you learned about what to expect during pregnancy?"*

ii Whether and under what contexts participants sought out biomedical information;

e.g., "Have you come across or actively searched for medical or scientific information about pregnancy, birth and motherhood? For what aspects of your pregnancy do you look to medical or scientific literature to learn about? (Or do you not engage very much with medical or scientific perspectives on pregnancy?)"

iii Specifically; in each group, participants were asked whether they were familiar with the term "epigenetics" and for those who did not recognize the term, a few popular headlines related to epigenetics were read to the group for reference. These particular headlines were selected as complements given they reflect diversity across several domains: (a) the degree of certainty communicated through language choice: "*permanently* influences," "*may* raise," "*could* pass on"; (b) the particular topical focus of article: diet, smoking, stress, exercise; (c) inclusion of one paternal study; (d) inclusion of a non-traditional media outlet, "whatisepigenetics.com" which—for the first author—appears within the top five Google search results using the term "epigenetics" and top two search results using the query "epigenetics pregnancy." Listed below are the headlines which were selected.

"Is the term "epigenetics" familiar to you? If yes, where and how have you interacted with it/learned about it?"

If not, here are some popular press headlines. What are your initial reactions to this information?"

a) *BBC: "Pre-pregnancy diet permanently influences baby's DNA" (Briggs, 2014)*
b) *Reuters: "Young male smokers may raise obesity risk in their future sons" (Earls, 2010)*
c) *NYTimes: "Inheriting Stress" (Gaisler-Salomon, 2014)*
d) *whatisepigenetics.com: "Parents Who Exercise Could Epigenetically Pass on Heightened Learning Ability to Their Children" (Kirkpatrick, 2018)*

iv Similarly, participants were asked whether they had engaged with any neuroscientific content during the perinatal period, and specifically whether terms like "mombrain" or "pregnancy brain" were familiar to them.

e.g "Have you encountered or heard of the term "mom brain"? If so, where have you learned about it and what does it mean to you? If not, what might it indicate?"

The first focus group was moderated by the first and last author, who both—to avoid influence (Krueger, 1998; Krueger and Casey, 2000)—refrained from participating in the discussion except to ask for clarification or further explanation and elaboration. Participants spoke on their own initiative and engaged with each other's responses. Focus groups lasted between two and two-and-a-half hours.

The methodology had to be adapted to the evolving COVID-19 pandemic restrictions. The first focus group was conducted in-person following the social distancing measures in Montréal at the time. It was held in a non-public space with a comfortable atmosphere. The first and last authors were present, as was a local birth advocate and postpartum doula. The presence of a doula for this first group discussion was intended to ensure comfort and security for participants, and to hold space for any mention of emotional difficulty. Due to changes in COVID-19 pandemic regulations, the following two groups were held over video conferencing platform (Zoom). This allowed for participants to join remotely from the comfort of their own homes. The Zoom groups were moderated by the first author only. Anticipating the pragmatic challenges for group rapport presented by a digital focus group, the last author and doula refrained from participating. The rational was to keep the group as small as possible, to enable the intimacy required for the participants to comfortably share their experiences. Though we decided to forego the presence of the doula in the Zoom sessions, participants were given the option to speak with her if they felt they needed to debrief. Conversation was felt to reach a comparable degree of intimacy across in-person and remotely orchestrated groups. On Zoom, however, though participants shared equally personal narratives to the first in-person group, discussion took on more of a turn-based form. In person, participants were more likely to prompt or interrupt each other in echoes of agreement, difference of opinion, or clarification. On Zoom, participants tended to mute their audio while others were speaking and there was often a pause in between speakers. All focus groups were audio recorded and transcribed; names were pseudonymized in transcription. Field notes of initial impressions about pertinent themes were made after each focus group.

Data Analysis

Focus group data were coded manually on paper and digitally. Thematic analysis was conducted by the first author; broad themes were identified and discussed among the authors. Any discrepancies that arose were resolved by incorporating the perspective of the last author. The analysis was guided by the overriding research questions, an awareness of a diversity of online sites and forms of research translation afforded by the scoping study of online sources of biomedical translations and the resulting awareness of the translation narratives circulating online, and the questions and discussion during the focus groups. Thematic analysis consisted of searching across the corpus of data and within individual focus group data sets.

Themes emerged in the data set vis à vis focus group participant responses to the prompts that guided the discussion. In this sense, themes emerged not only for their prevalence and relevance across data sets (at the level of individual participants and at the group level, across three separate focus groups) but also based on the emotional quality of certain content over others. The first categorization of transcribed texts resulted in an initial grouping of themes that was further refined through an iterative process with an increasingly interpretative lens.

Our analysis of the focus group data took two stages. Transcripts were read multiple times, and studied to identify the themes that related directly to our research questions. A second inductive approach was also employed by the first author to locate additional salient themes within the data, and discussed amongst the authors. Our thematic analysis was theoretical in nature and largely at the latent level: driven by the analytic interest in specific issues and concerned with the identification and examination of base assumptions or perceptions that influence the semantic content (Braun and Clarke, 2006). The categories of themes presented in our results section reflect semantic thematizing i.e., navigating biomedical and cultural perinatal information on the Internet and latent thematizing i.e., participants' narratives that provide evidence to certain psychological phenomena or reflect evidence of a particular cognitive mechanism at work, such as looping effects, that directly speak to the potential impacts of engagement with translations of biomedical research on the perinatal period.

Thematic analysis was contextualist, positioned between the poles of an essentialist or constructionist theoretical method: we sought to "reflect [the] "reality" of participants while also "unpick or unravel the surface of 'reality'" (Braun and Clarke, 2006).

The focus groups were lagged, separated by at least 1 month, which allowed for extended reflection between discussions.

RESULTS

The results include a demographic overview of our sample and the presentation of the three themes that emerged from our focus group data. The analysis and results presented here speak to the focus group data set reflected in **Tables 1**, **2**.

Sample Demographics

Our sample consisted of a total of 17 women. Four participants were pregnant at the time of discussion. All participants hailed from Montréal and the surrounding area, representing eleven different neighborhoods. The mean age of participants was 36. Listed occupation spanned a variety of industries and positions represented various rungs of institutional hierarchies (e.g., medical resident, operations manager, etc.). See **Table 1**.

TABLE 1 | Sample demographics.

Demographic categories	Frequency
GENDER IDENTITY	
Woman	3
Woman (she/her)	1
Female	10
She/Her (female)	1
Straight female	1
Cis gendered woman	1
AGE	
26	1
33	3
35	4
36	1
37	3
40	3
41	1
42	1
MARITAL STATUS	
Single	3
Married	10
Separated	1
Divorced	0
Conjoint	3
HOUSEHOLD INCOME	
25–50k	3
50–100k	7
100–200k	4
Over 200k	2
Preferred not to disclose	1
ETHNIC IDENTITY	
White	3
Caucasian	2
Canadian of Italian descent	1
Italian/Canadian	1
White, British, Jewish with immigrant parents	1
White Newfoundlander	1
Caucasian/French Canadian/Irish Canadian	1
Ukrainian	1
Latin American	2
Brazilian	1
Chilean/Latin American	1
Black	1
Preferred not to disclose	1

Focus Group Discussion Narrative Themes

On the basis of focus group material, three main thematic areas were identified: (1) A kind of brain (**Table 2.1**); (2) The looping effects of biomedical narratives (**Table 2.2**); (3) Imprints of past experience and the management of the future (**Table 2.3**). The results will be summarized in brief and elaborated upon in greater detail.

Theme 1: "A kind of brain" (**Table 2.1**) captures women's perspectives on the concept of "mombrain" or "pregnancy brain." This theme encompasses women's reflections on this "kind" of brain, discussing the extent to which this concept was validating or stigmatizing and how its popularization impacted their experience of pregnancy and motherhood. For some participants, the notion of "mombrain" provided the legitimization of and justification for their subjective experience of e.g., memory lapses or forgetfulness—the phenomenology subsumed under this term—during the perinatal period. For other participants, "mombrain" created expectations of incompetence and was the cause of worry. The brain-based explanation was considered to render the phenomenological experience more serious, permanent, and without obvious solutions. Alternative explanatory models were proposed e.g.,

TABLE 2 | Focus group discussion narrative themes.

Theme 1. A kind of brain	
1.1 "Mombrain" brain as validating subjective experiences	
1.1.1 Alice:	*But this most recent pregnancy, I was struggling a lot with stress and brain fog. Really feeling like I'd lost my edge. I'm not even me. Everything is like a soup. I was looking for academic research, "what are the effects of high levels of estrogen on cognition in women."… Looking for published research about what is there out there that might explain my subjective experience in terms of a scientific possible explanation...There's a bunch of stuff online that's kind of like, "mommy brain's not real." It's real. It's absolutely real...I can't think at all. And I feel like this is where I end up going. But I'm like, this has impact on my career. This has impact on my learning. This is an actual phenomenon. Not just women complaining. You know, not just women being lazy or whatever. But like an actual phenomenon that I can find no mention of in anything besides like pop reporting and that's why I started looking for, 'is there any actual research out there about estrogen levels and cognition?' That would legitimize what I'm subjectively feeling.*
1.1.2. Gabriella:	*I think [the neuroscientific terms] justifies why you do things. And then you can explain it to people, yeah that's scientific. (Laughs) Like it's not just a crazy me thing, it's an actual thing that happens to most women who are pregnant.*
1.1.3. Hailey:	*I do sometimes blame hormones for something which clearly originate the brain, but it's also another system. We like to call women hormonal and it can be negative, but at the same time sometimes I like to attribute it to a process that's happening within my body. Especially say like, postpartum, you have this adrenaline for a few weeks. And then, depletion, the baby blues or whatever. We kind of cry out of... I mean, I clearly want to attribute that to this hormonal shift that's happening in my body and not the fact that I can't control my emotions. And so I guess I use what works for me when I want it to...I feel like I legitimize certain things based on how I want to. It's not just, I can't control it. It's because there are these things happening in my brain and my body and learning about it can help to sort of think like, okay, oh, this is normal… Sometimes I want to use it for my benefit. Like I make an error in sending a letter or something like that. Well, I use it to my benefit when it works out, like a horoscope. When it doesn't work out, I don't like it.*
1.2 "Mombrain" as stigmatizing	
1.2.1. Louise	*I feel like we hear a lot about [mombrain] in popular culture. I clicked on something on the Internet the other day, I think it was something on PET scans [inaudible] like, there's less activity in the hippocampus in women who've given birth for some number of years afterwards. I've heard of things like that. So I know there might be some evidence to it. But still, like, I don't like the concept in general because I feel like for me, I went back [to work] like six months postpartum and I had exams to take and stuff like that. I kind of felt that the fact that this is a popular concept in media and the culture in general, I feel that I hope it doesn't contribute to people's impression of me at work when I'm back after having a baby, et cetera. So, in that sense like I didn't like it so much and I didn't find it to be true personally. Yes, of course, like if I didn't sleep well, then I was tired the next day, but I took like exams and stuff, maybe like a year-and-a-half postpartum and I did just as well as I had done on previous ones, so I feel personally, I was fine. It's not the greatest concept if it's going to discourage people from either doing things at work or if it's going to affect other people's perceptions of them. Just pretending it doesn't [occur] seems okay for me. So that's what I'm going to do.*
1.2.2. Beatriz	*I never felt someone was holding [mombrain] against me or saying, 'Oh, she was not as good because of that' or something. No. I never felt it. But I felt it myself, inside. I felt I was not being good enough. I feel, I forget. I put more pressure on myself because, Oh my God, why didn't I forget, is because of my mom brain? And I am like anxiously looking for [my memory] to go away again.*
1.2.3. Louise	*When the term brain fog is used, it sounds like it's something that's less correctable or you can't change it as much versus if you say, 'Oh, it's because I'm tired and I'm pregnant', well, there's an end to the pregnancy and you're not gonna be tired if your baby starts sleeping better. If you say that there's like a permanent or at least long lasting change; that pregnancy and being postpartum causes cognitive changes in the long run over several years, then I find it becomes problematic because when you return to work and there are expectations regarding your performance, you might feel as though if other people believe in this concept. The idea that there's brain fog makes it sound like you might be less competent versus if you say it's like hormonal changes or you're sleep deprived or it's the pregnancy: those are all things that come to an end fairly quickly. So they can't be used as a longterm performance problem. Because they specifically write an article that talked about there being changes that lasted at least up to three years based on their follow-up period in the study. I have experienced periods, especially like early postpartum when sleep deprivation is very prominent, I feel like I have a certain amount of brain fog, but I guess it's just that the idea that there's really some lasting change that has a negative effect is less appealing.*
1.2.4 Zoey	*But I, what I find frustrating [is that] there's this trope for so long about women can't be leaders because of our menstruation because when we have PMS, like we're crazy and wild. I think mom brain fits into the same thing where [the] narrative is compared against [a] male standard. Publicly, it's not like, wow, women are so powerful when they're in ovulation, they can be incredibly outgoing and charismatic and creative when they're in PMS, they're incredibly sensitive. The veil thins between the conscious and the unconscious, and we're in this period of being sort of shamanic beings. And so I think during pregnancy, there's this huge spiritual aspect that is totally ignored and repressed. And so the value and the power and the capacity for pregnant women to play this incredible role in society is downplayed. And instead, what, what gets projected out is, ah look she becomes a shitty employee... So I think it's just this patriarchal standard and it doesn't serve us. And it's kind of like pinpointing, like using against us what, you know, never is talked about in a meaningful way: men, because they have so much testosterone should not be leaders because they have a tendency towards war and aggression.*
1.2.5 Maya	*Around the brain fog first: the balancing of the narrative for me is the important thing. Cause it's like a big part for me. Doesn't like these hashtags, you know, hashtag brain fog, hashtag mom brain partially because of the impact that a lot of this stuff had on me in terms of like my work, you know, and the unspoken sense of not being as competent: obviously people not really being allowed to say so, but it's kinda there, you know, and there isn't exactly space for it. Right. So I just feel this real tension between wanting to acknowledge that this is a very real thing, right. Where I'm just like, 'my memory was wasn't as good', you know, like there's many ways in which I wasn't as capable in terms of being productive in a sort of capitalist productive way. I was very more creative and more able to do certain things, but definitely less able to do others.*
1.2.6 Phoebe:	*I've heard about pregnancy brain and stuff. Am I like just pointless to them once I become pregnant? And then eventually have a kid? That's like a huge thing that I'm dealing with. I'm trying to over-perform now so that I can be like, 'I can do two things at once'. I want to leave work on a high note and just like, remind them that I'm like still a good employee. So a lot of that pregnancy brain, mumbrain is a huge thing, I think, um, in terms of my career and how I think about work specifically, like, I don't, that's where I see like the measure for failure.*
1.2.7 Nina	*I think like the use of the word brain fog, like, you know, in some cases maybe it feels accurate, but like the universal use of it is probably because we have a tendency to like blame things on women and mothers in particular. So like to make it about the mother's brain is not really fair. You know, you might just be tired. I worked really a lot, like more than I probably should have the whole time I was pregnant up until the last, like three or four weeks when I took some time off. But I didn't find that there was a problem with my brain. I found that I was tired and I would take small naps in the afternoon.*

(Continued)

TABLE 2 | Continued

Theme 2: The looping effects of biomedical narratives	
2.1 Ripples of knowledge	
2.1.1 Louise:	*Like, you have your genes and your genes are supposed to be set in stone, except that there are environmental things that can cause changes in the gene that persist over the longterm. So like, example, what I've heard of is like, Oh, if there's stress in pregnancy, like COVID, like with my daughter. So I heard about that... like a big environmental event or multiple little ones that can change your genes, well they might remain changed that way down the road for many years and maybe even passed on for the next generation. Which is I think where the interest in pregnancy comes from... pregnant women and stress and how it could negatively impact the baby...I think it was in regards to like pregnant women and like some natural disaster that had occurred like either a flood or a fire somewhere.*
2.1.2. Nina	*I read a paper one time about, people who lived in the Warsaw ghetto during the second world war. Uh, and there was like a lot of food shortage and there was some potential longterm effect on their descendants of like body mass.*
2.1.3. Hailey	*I think it was the ice storm. I was surprised that like a two week period could have such an impact. This pandemic is going to go on for much longer, like say the Warsaw example, I mean that's quite more distinct in time. I was also part of another research study that looks at stress in pregnancy during the pandemic. And I think they are interested to see different markers cause they're also now asking for like either a hair sample or something else. The one thing that worries me is the impact of stress during pregnancy.*
2.1.4 Alice	*I was actually worried about epigenetic effects in the baby. Worrying maybe that they would be more sensitive to stress or what have you. I wasn't worried about things like Down's Syndrome or developmental… and I wasn't particularly worried about preterm labor or anything like that even thought I know that high stress can be associated with preterm labor. For me personally I wasn't really worried about that. I was confident in my physical health while I was pregnant. I was mostly concerned about my mental health and any potential epigenetic effects that would have on the baby… I deliberately avoided all forms of literature about effects on babies of stress in mothers because I was maximum stressed.*
2.1.5 Teresa	*Well, I'm stressed out today because life is stressful. But I shouldn't be stressed cause that will hurt my baby. It ratchets up all of the stress that you're feeling….there were some times that I was frightened and really angry and really unhappy and I was thinking I can't protect my baby from these feelings, from whatever's happening to me physiologically. So, I definitely did have those thoughts. What is the effect of this fight? This blowout? Me being frightened? Me being angry? Me being really hurt and I can't protect her from it.*
2.1.6 Gabriella	*I had so much trauma since January, my levels of cortisol were so elevated all the time and when I was working it was easier to be distracted by something so cortisol levels would come down but now my cortisol levels were so high all the time, all I could think about was, how is this going to affect her when she comes out? Right, because everybody tells you, you have to stay calm, you have to be so happy… I'm crying all the time, I'm loosing my mind, I don't know what's going on. And all I think about is, "cortisol is too high, I've gotta calm down."*
2.1.7 Charlotte	*Just to add to what you were saying about "knowing" and actually being able to do… if you know it's better to eat a certain way or to do…I was on anti-anxiety medication for many years and the fear was this medication, is it going to impact my unborn baby? If I'm finding other ways to self medicate, is that going to impact my baby? So it was a lot of weighing whose mental health is going to be more important: mine during this pregnancy and the potential impact that it has on my child or should I be focusing more on the unknown and my child's development while I may suffer mentally during the pregnancy? So it was kind of a battle to know this is probably not best for me to be on medication, but at the same time if I'm not then this is not going to be a healthy pregnancy for me…*
2.2 Ripples of risk and diagnosis	
2.2.1. Beatriz	*You do get flooded with all kinds of scary things. The talk about postpartum depression: it's so needed. It is. And of course, you know, you need to be aware of it, but just talking about having it was giving me so much anxiety that I was like every 15 days seeing a doctor to prevent postpartum depression that I never would have in the first place. And honestly, the doctor, he was great, but it wasn't that that saved me, you know, like it just didn't happen with my body. So it does create needless anxiety. I was dealing with a lot of anxiety and I was hearing that having postpartum depression was gonna be a sure thing for me. My mom had it for me after birth. So I was like it's going to happen to me, I have it in my genetics. So I prepared. I was afraid of it. As a mom, everything you hear, you get so afraid. I would say that it's the news and everything that comes out of it. It's so sensationalist. As a mother hearing about epigenetics and all this sensation about it...*
2.2.2. Zoey	*Women are taught to have so much fear during pregnancy*
2.2.3. Victoria	*Most [stories of pregnancy] are not positive stories; I think in pregnancy and motherhood we need to see more positive birth stories. When I was in England, that was a very, very important discussion. There was a lot of groups to share positive birth stories you know, most of the times we get more into the negative and we of course can freak out. Positive stories are super important. I think if we could get a balance, you know, between positive and negative birth stories...*
Theme 3: Imprints of past experience and the management of the future	
3.1 Translational trauma	
3.1.1 Maya	*Um, similarly I heard something again, I don't know how verified it is. Someone sent me an article [about epigenetics]. I think it is that their experiences or traumas, this got imprinted on their DNA in some way. And that that gets passed down. And I remember being, first of all, it just seems so sci-fi that, really, it like sticks to your DNA, that experience? Then I got nervous cause I was like, Oh my God. Thinking about my grandmother's experiences. And then thinking about my own son and, and you know, my partner's mother and then my mother and just being like, I have no control over this, you know, they've been through so much, he's going to experience that on some level maybe.*
3.1.2. Victoria	*I think it also has a lot to do with the idea I was suggesting before that the brain is plastic. You can always change it, you know, in a positive or wrong way, but it can be changed...There's also a lot of negativity about epigenetics. We forget, or maybe we don't know much, but with epigenetics, we can also do positive things. Life gives us the chance to change it again and to make it right. I think it's positive to be aware of the concept to try to understand we can use it for positive.*

(Continued)

TABLE 2 | Continued

3.1.3. Victoria	*"I'm very familiar with neuroscience, especially now, with the kids getting older. I read a lot and most of it has to do with neuroscience and the way the brain is shaped and how the early years are super important...So the experiences you get are very, very important, especially in early years. Even though you don't have your dream birth or the best pregnancy, the thing is that you can change it, you can, you can always do better...I think it also has to do with the way you parent…little rats: one didn't have like the mother who would [care for her baby] mouse. They moved it with a mother who had [caring behavior] and that little rat with no genes to be caring when she became a mom, she was caring too. So the expression of the change of the gene suggests that we can change the way we help our kids...You know, you have every day to make it better and every day to achieve a positive experience with your kids.*
3.1.4 Beatriz	*They take a scientific paper, they take one piece of information, they make it a big headline. And then they talk about it like it was the end of your life. Your child is going to be abuser or is going to be a rapist because your grandfather was. It's like, it's they take it out of context and it creates so much anxiety. And it's like, no, you know, it's such a small thing. The body has so many protection mechanisms. That it's not because something happened in the past, they're doomed to happen again. So balancing that perspective with being in the middle of the feeling and receiving all that information, you know, it's kind of hard for me and I kind of forgot about my theory, forgot about what I knew. I forgot about the deeper analyses and inside me I was like, Oh my God. And I had to remind myself, no, I dyed my hair, but my baby is going to be fine. And my grandmother killed herself when she was 40, but I'm going to be fine. My baby's going to be fine. It's a lot of work. I find that it's a lot. It's intense.*
3.1.5 Efe	*I've heard the term epigenetics here and there. And so I had like a vague idea about it that, the things that you do in your life will have... you have power in influencing your genes. I'm an adopted person and I don't know anything about my family. I don't know anything about like my genetics. I kind of sort of felt like a blank slate. Not because I am, it's just the reason why I'm here in Canada was because of, you know, war in my country of origin. That's why I was, that's why I got adopted. That's why I'm here. So it's like, I know that there is a lot of, you know, trauma in my background. I'll just live my life and do the best I can. I don't know anything about [my background], so I do think about it, but the only thing that I can do is my best. So I'm not, I don't really want to like put too many ideas in my head because it's just like, we don't know. It's too up in the air for me. Like it's just very abstract.*
3.1.6 Rosa	*There was child abuse included in the list of things in the generations before me and me included. And I was very scared of, because I didn't understand. I thought it was more like you will end up by, um, attracting that to you because of the way you act or the way you relate to people. I never considered that it was in DNA. So I'm like, okay, how do I stop the child abuse? I'm very stressed and anxious about it. So I did go to a psychologist that is dedicated to children. And I'm like, okay. So how do I prevent my child from being in a situation like this?*
3.2 Responsibilization of the mother-to-be	
3.2.1 Alice	*Something that's so frustrating about that—whether it's epigenetics research or just like 'eat well because it has an effect on the baby—sometimes that's accessible and sometimes it's not. Particularly the things that are out of an individual person's control. It made me angry at our society. This is ridiculous. It's like we have information telling us that having elevated cortisol levels and super high stress is absolutely associated with negative outcomes. But, there's no support for you. You have no job. Do the things. Go ahead. But, keep going and eat a fucking salad. I think particularly in the context of being a pregnant mother with an innocent, helpless human inside of me who I'm solely responsible for, it feels like a huge weight of responsibility.*
3.2.2 Teresa	*I think that there was some part of me that was very stubborn about resisting that kind of information because I felt like that it wasn't something that I should have to take on: that I should have to be worrying about every single thing I thought or felt or did. And so there was some part of me that was very rebellious that way. And then every once and a while I would get sucked in and it would cause me this terrible anxiety and I would have to go back and sit and think about what do I want, how do I feel? Do I feel healthy? Or in the cases where after my child was born I would look at her and go, 'does she look happy, does she look healthy?' Constantly trying to pull myself back to that because of this glut of information.*
3.2.3 Teresa	*The other frustration for me which is less personal, it's more social, was this information should be used to make structural changes to lessen stressors on people's lives...We seem to have this idea that regardless of the science whether it's positive things you can do or negative things you shouldn't do, it still places enormous expectation on individuals.*
3.2.4 Zoey	*There's a lot of moralizing that goes on around pregnancy.*
3.2.5 Alice	*When I think back to 15 years ago when I was pregnant with my first daughter—I don't talk about this much because I was trying to fit into mom society—I was 19 and I was pregnant and we lived in my car. And we kept trying to apply for welfare and they kept denying the application. And we were eating at the food bank…that does a hot lunch every day…so our whole life was going around in this broken ass uninsured car…that I couldn't get inspected cause we had no money. Go to one place to line up, get whatever they're serving. And it's mostly bread. And go to the other place for dinner and it's mostly bread. And you go to the food bank and they give you frozen expired yogurts that are all aspartame and granola bars that are all aspartame and like a two liter of Nestle Quick Powder and more bread and some pasta and a can of beans and then you're reading, "I need to be getting adequate nutrition" but if it's beyond your control to do that then it leaves a lot of stress on the individual without any societal support. Things that you can't change, wish you could, but are educated enough to know that they might have a negative effect on your child, it's infuriating to me.*
3.2.6 Louise	*I feel that there was somebody…who gave an interview to the press about like women, pregnant women and stress and how it could negatively impact the baby. Except that this article came out in like April or March maybe. And I was due in May and of course I had already been stressed due to the pandemic. Oh geez. It kind of sucks when it's something that happened and you have limited control over it. Cause I think I remember like the initial time I heard about [epigenetics], I think it was in regards to pregnant women and some natural disaster that had occurred like either a flood or a fire somewhere. So that seems like very far away to me when I heard first heard about it. Cause I was like, Oh, you know, that's interesting. But you know, of course: pandemic. So I got my own little taste of that with this one.*

sleep deprivation and hormonal shifts. Some interlocutors felt that the interpretation of biological difference aids a societal construction of female limitation.

Theme 2: "The looping effects of biomedical narratives" (**Table 2.2**) addresses several impacts of biomedical narratives on the expectations and the experience of the perinatal period. Women discussed their engagements with translations of epigenetics and neuroscience as anxiety-inducing. Participant narratives revealed that consumption of knowledge translations of epigenetic research increased scrutiny and awareness of mental states, creating distress around the current or anticipated presence of stress, anxiety, and depression and the potential impact on the baby. This theme reflects that engagements with epigenetic research translations have the potential to precipitate and perpetuate distress inducing categorical loops and bioloops (Hacking, 2000).

Theme 3: "Imprints of past experience and the management of the future" (**Table 2.3**) is linked to the concepts of epigenetic inheritance, permanence and plasticity and the societal responsibilization of the mother/-to-be. The engagement with epigenetic research translations discussing transmission of trauma at the layer of the epigenome left some women with a feeling of incapacity to control or act upon past experience. This was a source of distress. Other women discussed the concept of plasticity as proof of their ability to repair and enhance, conferring a sense of agency. This potential ability, agency and biological flexibility, for some implied an overwhelming degree of responsibility and blame-ability. A number of participants voiced frustration that translations of epigenetic and neuroscientific study supported an imperative for them to monitor their bodies to mitigate risks and promote optimization of their children.

RESULTS

Our findings cast light on how engagement with translations of epigenetic and neuroscientific research impacted women's perinatal experience, wellbeing, and self-construal. At best, the narratives and framings of translated scientific research can alleviate feelings of guilt and stigma. At worst, they can reinforce stigma and evidence suggests that data is being mobilized to create stigma against women from disenfranchised backgrounds, with echoes of eugenics from decades past. (Richardson et al., 2014; Lappé, 2016). The neuroscience gives rise to a new "kind of brain": the "pregnant brain" or "mombrain." This "kind of brain" for some serves to legitimize subjective experiences of change and challenges during the perinatal period for others this biologization increases/results in stigmatization of women of childbearing age. The authority of neuroscience and epigenetics in our society confers a high status of truth to this knowledge. Women's narratives attest to the epistemic status of these forms of evidence to bring about perpetuating cycles of distress. Interpretations of epigenetic science revealed tensions between perceptions of determinism, biological damage, lack of agency, and potential pressure experienced by narratives of plasticity and opportunity for optimization. In line with existing analyses in the literature, the translations of these knowledges also confer responsibilization of the individual and create imperatives of self-monitoring.

Theme 1: A Kind of Brain

Respondents interpreted the popular science and public health literature on neuroscience and epigenetics as evidence that points to a particular "kind of brain," a configuration of the brain's structure and function specific to pregnancy and early motherhood.

Mombrain as Validating Subjective Experience: "It's Not Just a Crazy Me Thing, It's an Actual Thing"

On December 19th of 2016, Nature Neuroscience published a paper, "Pregnancy leads to long-lasting changes in human brain structure" (Hoekzema et al., 2017), that was immediately picked up by major traditional news outlets like *The Scientific American*, *Science Magazine*, *The New York Times*, all communicating with slightly different words, the "take-away" from the study: "Pregnancy Causes Lasting Changes in a Woman's Brain: New mothers showed evidence of neural remodeling up to two years after giving birth" (Caruso, 2016). This paper reported significant pre- and post-birth reductions in gray matter volume of brain regions including several cortical areas in addition to the hypothalamus, amygdala, nucleus accumbens, and hippocampus (Hoekzema et al., 2017). Although neuroscientific research on cognitive performance or memory decline (during pregnancy) remains largely inconclusive (Barha and Galea, 2017; Duarte-Guterman et al., 2019) its uptake in lay media and its ascription to increasingly common notions of "pregnancy brain," "mombrain," or "brain fog" does not always reflect this. A New York Times piece proposes cognitive deficit or memory loss as an attunement to infant needs: *"It may be that some subtle aspects of memory are sacrificed to enhance other areas of cognition"* (Sacks, 2018). WebMD's treatment of the subject follows the same formula: *"It has been postulated that, from an evolutionary standpoint, this memory impairment may be helpful so that women will forget about other stuff and focus on caring for the child"* (Mann, 2014). Examples of the notion of a trade-off between cognitive function and having children can be found across the social media sphere: posts by pregnant women and new mothers on Instagram incorporate this rhetoric into their communications, performances, and self-construals (**Box 1**).

The majority of women in our sample were familiar with the terms "pregnancy brain," "mombrain," and "brainfog." Discussion highlighted two dominant reactions to these terms that revealed tensions between women's personal relationship to the phenomenon and their feelings about its implications in society. A number of women fervently asserted that forgetfulness, memory lapses, or absentmindedness during the perinatal period—the phenomenology subsumed under the concept of mombrain—are not imagined phenomena: "*mombrain is real*" (**Table 2: 1.1.1**). In their minds, they were not as capable during pregnancy and motherhood as they had been before. To these women, brain research played a legitimizing role. Their forgetfulness could be justified by the brain; public dialogue substantiated the prevalence of this subjective experience and provided authoritative proof of its realness. In the words of one participant, Gabriella, *"I think [the neuroscientific terms] justifies why you do things. And then you can explain it to people, yeah that's scientific. (Laughs) Like it's not just a crazy me thing, it's an actual thing that happens to most women who are pregnant."* (**Table 2: 1.1.2**) Another participant, Alice, described her active search for emergent neuroscience research demonstrating links between pregnancy and cognitive deficit:

> *"But this most recent pregnancy, I was struggling a lot with stress and brain fog… I was looking for academic research, "what are the effects of high levels of estrogen on cognition in women."… Looking for published research about what is there out there that might explain my subjective experience in terms of a scientific possible explanation...There's a bunch of stuff online that's kind of like, "mommy brain's not real." It's real. It's absolutely real... This is an actual phenomenon. Not just women complaining. You know, not just women being lazy or whatever. But like an actual phenomenon*

that I can find no mention of in anything besides like pop reporting and that's why I started looking for, 'is there any actual research out there about estrogen levels and cognition?' That would legitimize what I'm subjectively feeling." (**Table 2: 1.1.1**)

The neurosciences are positioned to change our understanding of ourselves as "cerebral subjects" (Vidal, 2009). The explosion of brain research has solidified the brain as the organ that houses the "self." For this participant, behavior is rooted in the brain and thus her understanding of herself is sought via neuroscientific proof. The brain rhetoric is validating: it relieves prior self-judgment and the presumed judgment of others who portend that she's "[just] complaining or "being lazy" (**Table 2: 1.1.1**). This language and base assumption is reflected in certain media portrayals that clarify mombrain is i.e., "backed up by science" (Gordon, 2020) and not just a "convenient excuse for forgetfulness" (Gordon, 2020). Alice's language suggests she has internalized the suspicion that women are unduly complaining or making convenient excuses for their incompetence. Becoming the "cerebral subject" (Vidal, 2009), however, is defense against this critique.

Mombrain as Stigmatizing: "[The] Longterm Performance Problem"

The other presiding reaction to "pregnancy brain" and "mombrain" was one of apprehension. These participants suggested that regardless of whether they had experienced memory challenges in the perinatal period—some had, others had not—they were uncomfortable with the framing of such experiences in neurobiological terms. To these women, compromised cognitive functioning was more aptly interpreted as ramifications of heightened multitasking or lack of sleep. For them, the popularization of brain rhetoric was a threat to the perception of their competence and to their wellbeing, personally, and interpersonally.

"I feel like we hear a lot about [mombrain] in popular culture. I clicked on something on the Internet the other day, I think it was something on PET scans like, there's less activity in the hippocampus in women who've given birth for some number of years afterwards. I've heard of things like that. I know there might be some evidence to it… I hope it doesn't contribute to people's impression of me at work when I'm back after having a baby, et cetera. Yes, of course, like if I didn't sleep well, then I was tired the next day, but I took like exams and stuff, maybe like a year-and-a-half postpartum and I did just as well as I had done on previous ones, so I feel personally, I was fine. It's not the greatest concept if it's going to discourage people from either doing things at work or if it's going to affect other people's perceptions of them. Just pretending it doesn't [occur] seems okay for me. So that's what I'm going to do." (**Table 2: 1.2.1**)

Louise and others conveyed a conscious act of preferencing one explanation over another. This participant privileged a sleep narrative, choosing to ignore the brain narrative. This description reflects a dichotomization present in the public dialogue: the phenomenon in question—i.e., forgetfulness—is caused either by the brain or by chronic lack of sleep. This dichotomization may arise and be perpetuated at numerous points in the production and translation of a scientific finding. The design of the study itself may not take an integrative or "ecosocial" view of the brain (Kirmayer, 2019), but instead treat the brain in isolation from its environment, neglecting critical contextual factors that influence the results. In the translation and uptake of neuroscientific study, descriptive findings may be interpreted as causal. What is often absent from design or dialogue is the notion that "brains in question" as subjects of study do not exist in a vacuum, but in complex interaction with their surroundings. The narrative based in the brain and the narrative based in the social world are not at odds with each other, but are different levels and lenses on a particular phenomenon each with their own affordances and limitations.

Many of our participants were fearful of the stigma brain-based explanations could bear. Phoebe disclosed that she was "over-performing" at work during her pregnancy as a compensatory measure (**Table 2: 1.2.6**). She presumed that her colleagues would perceive her incompetent due to "pregnancy brain" and later, "mombrain." This sentiment was echoed. Beatriz suggested that although she did not feel anyone "[held mombrain] against [her]" during her first pregnancy, she harbored feelings of personal inadequacy and was constantly in fearful anticipation that her brain would fail her: *"Oh my God, why did I forget, is because of my "mombrain"?"* (**Table 2: 1.2.2**). For these women, the anxiety of the brain-based explanation of the phenomenological experience revolved, in part, around the premise of seriousness and permanence.

"When the term brain fog is used, it sounds like it's something that's less correctable... less competent versus if you say it's like hormonal changes or you're sleep deprived or it's the pregnancy: those are all things that come to an end fairly quickly. So they can't be used as a long term performance problem. Because they specifically write an article that talked about there being changes that lasted at least up to three years based on their follow-up period in the study." (**Table 2: 1.2.3**)

An explanation in terms of sustained alterations in neural architecture constructs what is felt as a prolonged and insurmountable obstacle as opposed to a passing physiological state. The attribution of the phenomenology to sleep deprivation has a clearer, more practically actionable solution than if the narrative focus is on changed brain morphology. For the highly cited paper, "Pregnancy leads to long-lasting changes in human brain structure" (2017) the researchers claim the observed structural alterations are connected to the "biological process of pregnancy rather than to experience-dependent changes associated with approaching parenthood" (Hoekzema et al., 2017). A methodological examination of the degree to which these researchers are able to solidly make this claim is beyond the scope of this paper. The public participation in neuroscience, however, tends toward non-critical acceptance and as the transmutations of research papers become more distal, it is possible that the likelihood for misconstrual of sound conclusions is heightened.

A few participants drew a connection between the rhetorical use of "pregnancy brain," and "mombrain" to

that of "Pre-menstrual syndrome (PMS)." Though they did not dispute the phenomenological experience of e.g., memory lapses, they were fearful that "mombrain" might be leveraged as a means to discredit via assumed inferiority to men.

> *"But I, what I find frustrating [is that] there's this trope for so long about women can't be leaders because of our menstruation because when we have PMS, like we're crazy and wild. I think mom brain fits into the same thing where [the] narrative is compared against [a] male standard...And so the value and the power and the capacity for pregnant women to play this incredible role in society is downplayed. And instead, what, what gets projected out is, ah look she becomes a shitty employee... So I think it's just this patriarchal standard and it doesn't serve us."* (**Table 2: 1.2.4**)

Another participant, Maya, expressed that she felt tension between denial and acknowledgment of the implications of "mombrain." Maya's words highlight a common misconstrual. The studies purporting to show volumetric reductions in particular brain regions are not only contested but do not imply that cognitive deficits follow. Maya feels, however, the interpretation of biological difference gives way to a societal conception of female limitation and meaning-making through a strictly capitalist lens.

> *"Around the brain fog first: the balancing of the narrative for me is the important thing. Cause it's like a big part for me. I don't like these hashtags, you know, hashtag brain fog, hashtag mom brain partially because of the impact that a lot of this stuff had on me in terms of my work, you know, and the unspoken sense of not being as competent… So I just feel this real tension between wanting to acknowledge that this is a very real thing, right. Where I'm just like, 'my memory was wasn't as good', you know, like there's many ways in which I wasn't as capable in terms of being productive in a sort of capitalist productive way. I was very more creative and more able to do certain things, but definitely less able to do others."* (**Table 2: 1.2.5**)

This participant highlights the bind in which she finds herself, meriting a balancing act. To reject or downplay the feeling that her memory suffered during her pregnancy would be insincere, yet to acknowledge this phenomenon as #mombrain is to submit herself to a position of inadequacy by societal metrics.

Theme 2: The Looping Effects of Biomedical Narratives

Epigenetic research establishes new meanings for perinatal mental health: the mental health of the mother impacts not only her, but her child. Research suggests that the experience of depression, stress, and anxiety during pregnancy may have negative effects on fetal growth and development (Arabin and Baschat, 2017; DeSocio, 2019), that maternal prenatal stress programs infant stress reactivity (Palma-Gudiel et al., 2015; Arabin and Baschat, 2017) and that high levels of circulating cortisol alter patterns of infant brain connectivity (Bock et al., 2014). Research points to the care a newborn receives bearing impact on the development of neural systems. The widely popularized pup-licking paradigm implicates maternal mental health and behavior toward the infant in the generation of differential responses to stress for that infant down the line (Meaney and Szyf, 2005). Though studies point to multifarious specific risks and affronts, actual impact to the child is defined by multifactorial and complex dynamics between both risk and protective factors. Attachment theories predate epigenetic findings, but the genetic lens—as opposed to the psychological one—may have a validating effect and increase the perceived seriousness and pressure felt by women who engage with this research. Women face a new moral imperative to monitor their perinatal mental health for the safety of the infant, constantly assessing the "normalcy" of their psychological state.

Ripples of Knowledge: "Concerned About My Mental Health"

As her group's discussion turned toward epigenetics, Louise reflected:

> *"Your genes are supposed to be set in stone, except that there are environmental things that can cause changes in the gene that persist over the longterm. So like...if there's stress in pregnancy, like COVID, like with my daughter... like a big environmental event or multiple little ones, that can change your genes. Well, they might remain changed that way down the road for many years and maybe even passed on for the next generation. Which is I think where the interest in pregnancy comes from... pregnant women and stress and how it could negatively impact the baby... in regards to… some natural disaster that had occurred like either a flood or a fire somewhere."* (**Table 2: 2.1.1**)

Participants had engaged with epigenetic research translations ranging from: the impact of food shortage on body mass of the descendants of individuals living in the Warsaw ghetto during the Second World War (**Table 2: 2.1.2; 2.1.3**), the repercussions of natural disasters like a massive ice storm that struck eastern Canada and New England in the late 1990s (**Table 2: 2.1.3**), the COVID-19 pandemic (**Table 2: 2.1.1; 2.1.3; 3.2.7**), intergenerational transmittance of trauma experiences (**Table 2: 3.1.1; 3.1.4; 3.1.5; 3.1.6**), and the impacts of compromised mental health issues (including stress, anxiety, and depression) (**Table 2: 2.1.3–2.1.7**) during pregnancy, specifically, which materialized as the most concerning theme for the majority of participants.

> *I was actually worried about epigenetic effects in the baby. Worrying maybe that they would be more sensitive to stress or what have you. I wasn't worried about things like Down's Syndrome or developmental… I was confident in my physical health while I was pregnant. I was mostly concerned about my mental health and any potential epigenetic effects that would have on the baby…* (**Table 2: 2.1.4**)

Many of our participants had engaged with epigenetic research translations suggesting an association between perinatal mental health issues (e.g., stress, anxiety, and depression) and negative impacts for their children. This information was deeply unsettling. Analysis of womens' narratives reveal that, for a number of participants, engagement with epigenetic research

translations precipitated a heightened level of awareness including increased self-monitoring and concern for mental and emotional life during the perinatal period.

> *Well, I'm stressed out today because life is stressful. But I shouldn't be stressed cause that will hurt my baby. It ratchets up all of the stress that you're feeling… there were some times that I was frightened and really angry and really unhappy and I was thinking I can't protect my baby from these feelings, from whatever's happening to me physiologically. So, I definitely did have those thoughts. What is the effect of this fight? This blowout? Me being frightened? Me being angry? Me being really hurt and I can't protect her from it.* (**Table 2: 2.1.5**)

Ordinarily, fluctuating emotional states may be dismissed as everyday ups and downs (Kirmayer and Sartorius, 2007). Pregnancy, as a period of constantly emergent change may present a wealth of these acute, transient moments of bodily distress. The recent widespread dissemination and uptake of epigenetic and neuroscientific research may offer a lens that constructs a situation where potentially transient bodily fluctuations and distress risk being experienced and reframed in more medicalized and "at risk" terms. When such acute yet fleeting experiences of stress occur during pregnancy, their ascribed meaning may now be influenced by the belief that such stress harms the child. Mechanistic descriptions of methyl groups and histone modifications authoritatively convey the effects of stress that transcend the maternal body as assaults to the infant. The stress has become more dangerous and sticky. The knowledge of the consequential severity of a stressed condition may increase a woman's bodily preoccupation, which may increase the salience and severity of the perception of stress, leading to further emotional arousal.

The narratives of our interlocutors expose this heightened level of awareness and self-monitoring induced by pre-emptive categories of "at-risk" that emerge as part of epigenetic research translation through cognitive-interpretative and social-interactional looping processes (Kirmayer and Gómez-Carrillo, 2019). Processes of biolooping at the intrasubjective level couple bodily enactment and physiology (Hacking, 2000; Kirmayer and Gómez-Carrillo, 2019) that can change the course of perinatal experience, leading to symptom amplification, heightened distress, and reduced functioning thereby reinforcing the very experiences that epigenetic research warns of. Through processes of classificatory looping at the intersubjective level the pre-emptive "at risk" becomes actualized through its mere potentiality as a category. Perinatal distress is not only exacerbated but the woman becomes one of a kind: an epigenetic risk factor for her offspring. In Hacking's conceptualization of classificatory looping, "kinds" of people emerge via the authority of expertise and classification systems of science (Hacking, 2000; Seligman, 2018). Hacking proposes that these two types of looping effects may occur simultaneously and be "mutually reinforcing" (Hacking, 2000, p. 109).

As epigenetic research findings leave the laboratory, enter the mainstream press, and manifest in various forms, nourished by numerous actors, their significance is reinforced, and they become ubiquitously established in the pop science realm. Once a woman becomes privy to this body of science and way of thinking, she is but a few clicks away from accessing a colossal number of its instances which can influence how she makes meaning of her experience, defines herself, and understands her relationship to her body, mental health, and child. Hacking's biolooping notion highlights the capacity for a "change in our ideas [to] change our physiological states" (Hacking, 2000, p. 109). Through the engagement with authoritative epigenetic narratives, prevalent across various media forms and medical locales, women's ideas and beliefs on this topic can come to shape their bodily sensations and states.

An enduring loop may not only increase self-monitoring but prompt the self-assessment or categorization as "sick": a someone with a hazardous, pathological level of stress. Through this chain reaction (loop), a transient experience of stress may well reach a threshold and become disabling through a "vicious circle of symptom amplification and chronification" (Kirmayer and Sartorius, 2007). This bioloop is exposed by Gabriella's words:

> *"I had so much trauma since January, my levels of cortisol were so elevated all the time and when I was working it was easier to be distracted by something so cortisol levels would come down but now my cortisol levels were so high all the time, all I could think about was, how is this going to affect her when she comes out? Right, because everybody tells you, you have to stay calm, you have to be so happy… I'm crying all the time, I'm loosing my mind, I don't know what's going on. And all I think about is, "cortisol is too high, I've gotta calm down."* (**Table 2: 2.1.6**)

How does one find respite for this self-perpetuating loop of intensified self-monitoring and amplification of stress, worry, or pessimism? Charlotte, who had managed her anxiety with pharmacological intervention, discussed the dilemmas she had encountered in finding relief during her pregnancy. If she refrained from medicating and left her anxiety unchecked, the anxiety could harm her baby. Concurrently, she harbored concern about the potential impacts of medication: "*So it was kind of a battle to know this is probably not best for me to be on medication, but at the same time if I'm not then this is not going to be a healthy pregnancy for me*" (**Table 2: 2.1.7**). The experience of this participant reveals the double-bind consequences of epigenetic findings for mothers-to-be: which is more harmful? An "unhealthy" pregnancy and the epigenetic impact of manifested anxiety or the unknown ramifications for the child from medicating while pregnant?

Ripples of Risk and Diagnosis: "It's Going to Happen to Me"

Al-Gailani (2014) writes that the research interest, ease of uptake, and widespread establishment of folic acid as a necessary preventive measure for women of childbearing age was possible due to the construction of spinal bifida as an "urgent problem for the medical profession, charities, and society at large." Like folic acid for its time, issues of mental health have captured popular attention in recent years, increasingly defined as public health emergencies. Not only is depression more widely viewed

as a "free-standing, biologically-based" (Summerfield, 2006) brain disease, but, coupled with the lens of epigenetic and neuroscientific research related to "the maternal brain," is also viewed as a disease that can have lasting biological impacts across generations. The affective heft of current discourse on the maternal brain may rely in part upon the context of society in the "grips of a mental health crisis" (The Centre for Addiction Mental Health, 2020).

The feeling that one's pregnancy or postpartum is abnormally unhappy or difficult can be reinforced by the increasing public awareness of depression as a grave, brain-based disease that afflicts many women. Postpartum depression, specifically, has great traction in public sphere. At the time of writing the following Instagram hashtags had a traction of #PPD (288k posts), #postpartumdepression (322k posts), #postnatalanxiety (22.8k posts), #normalizementalhealth (17.2k posts), #honestmomconfessions (122k posts). For someone experiencing some degree of postpartum distress, reading about the prevalence of depression and anxiety, engaging with research translations that confer a high truth status to the seriousness of mental disorders, or interacting with others' personal accounts of #PPD on social media, can either have a supportive, validating effect on their experience of distress as abnormally unhappy, or increase their attention to their distress and support self-diagnosis, or a mix of both.

It is possible that the siloes and echo chambers that the Internet, especially social media, fosters, lead to myopic engagements with a type of content and increase patterns of looping. Beatriz reflected on how her engagement with PPD narratives online had provoked considerable anxiety and contributed to the belief that she would develop PPD.

> *"You do get flooded with all kinds of scary things. The talk about postpartum depression: it's so needed. It is. And of course, you know, you need to be aware of it, but just talking about having it was giving me so much anxiety that I was like every 15 days seeing a doctor to prevent postpartum depression that I never would have in the first place...So it does create needless anxiety. I was dealing with a lot of anxiety and I was hearing that having postpartum depression was gonna be a sure thing for me. My mom had it for me after birth. So I was like it's going to happen to me, I have it in my genetics. So I prepared. I was afraid of it. As a mom, everything you hear, you get so afraid. I would say that it's the news and everything that comes out of it. It's so sensationalist. As a mother hearing about epigenetics and all this sensation about it…"* (**Table 2: 2.2.1**)

Diagnostic labeling is a cultural artifact that can provide a meaning for hardship, an understanding of the seriousness of a condition, and a means of communicating its significance (Kirmayer and Sartorius, 2007). The act of taking on a diagnostic label can alleve distress associated with uncertainty and affords the individual a map of therapeutic possibilities and social consequences (Kirmayer and Sartorius, 2007). PPD was removed as a diagnostic category in the The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), but the popular uptake and attention to postpartum depression as a unique and distinct affliction—served by campaigns to raise awareness, destigmatize its diagnosis, etc.—has meant that the PPD label still widely circulates idiomatically in society as part of a cultural vocabulary, despite its removal as a discrete psychiatric entity. The continued lay use of PPD to explain distress during the postpartum period may also be supported by the public understanding of depression—writ large—as a disease of the brain. Neuroscientific inquiry on the perinatal period and the popularization of the "pregnant brain" or "mombrain" as a particular "kind" of brain, may contribute to the ongoing PPD rhetoric in society. To what degree do the descriptions of neural remodeling during pregnancy and interpretations about their meaning (that disseminate across the Internet) support the idea that PPD is an *expected* byproduct of such structural and functional brain changes brought about by pregnancy? The conclusion of one scientific article explicates an alleged connection between documented pregnancy and postpartum brain plasticity and a predisposition to mental disorders:

> *"A compelling body of evidence in healthy women and other female mammals confirms that, during pregnancy and the postpartum period, hormones and sensory interactions with the offspring relate to complex structural and functional changes in the brain.…Although this maternal brain plasticity facilitates a higher purpose—the continuation of the species—it is not necessarily innocuous and predisposes the mother or mother-to-be to peripartum mental disorders." (Barba-Müller et al., 2019)*

Seeking out readily available biomedical translations that discuss prevalence of PPD[2] or point to connections between documented changes in the "maternal brain" and compromised mental health, as well as interaction with others' PPD narratives, may all be factors that increase preoccupation and self-monitoring of affective states and bodily sensations that are then identified, labeled and given meaning in psychiatric terms. The comparison, internalization and interaction with boundless expressions, descriptions, and communications of distress online may serve as social reinforcement that catalyses the symptom amplification characteristic of biolooping and assumption of a sick role, characteristic of categorical looping.

Our data speaks to the possibility that the web of epigenetic and neuroscientific translations and the sociocultural environment of the digital sphere—an increasingly dominant space—may be exacerbating women's experience of emotional distress or the propensity and ease at which individuals may fall into looping trajectories.

Theme 3: Imprints of Past Experience and the Management of the Future

Translational Trauma

The allure of epigenetic narratives may rest on the following notion: we may not have control over our genes, but we do have control over the experiences that influence expression of our genes. But we cannot control the past experiences of our parents or grandparents. So, what then? Though at its essence, epigenetic

[2]Barba-Müller et al. (2019) state "The most common [mental problem] is postpartum depression (PPD), with an estimated 11–20% of new mothers suffering from minor and ∼7–14% from major depression (Gavin et al., 2005; Almond, 2009; Kirmayer and Gómez-Carrillo, 2019)."

research points to biological flexibility, a prominent rhetoric often propagated in the public sphere is one of fixity, not so dissimilar to the deterministic narrative of genetics. Preliminary epigenetic research exploring biological transference of trauma, specifically, is a subject that has received considerable media attention. Science Magazine, published a piece titled, "Parents' emotional trauma may change their children's biology. Studies in mice show how."

> *"But today the hypothesis that an individual's experience might alter the cells and behavior of their children and grandchildren has become widely accepted..."This is really scary stuff. If what your grandmother and grandfather were exposed to is going to change your disease risk, the things we're doing today that we thought were erased are affecting our great-great-grandchildren""* (Curry, 2019)

The evidence of intergenerational transmittance at the layer of the epigenome was a subject of concern for a handful of participants whose family history was mired in hardship. Maya shared:

> *"Um, similarly I heard something again, I don't know how verified it is. Someone sent me an article [about epigenetics]. I think it is that their experiences or traumas, this got imprinted on their DNA in some way. And that that gets passed down. And I remember being, first of all, it just seems so sci-fi that, really, it like sticks to your DNA, that experience? Then I got nervous cause I was like, Oh my God. Thinking about my grandmother's experiences. And then thinking about my own son and, and you know, my partner's mother and then my mother and just being like, I have no control over this, you know, they've been through so much, he's going to experience that on some level maybe."* (**Table 2: 3.1.1**)

In our sample, it appeared that women who had engaged with translations of epigenetic research discussing the biological inheritance of trauma felt demoralized by this knowledge. The perceived inability to control or act upon past experience with the subsequent feeling of becoming a powerless vector of troubled histories was a source of distress. While certain participants felt distressed by what was understood to be permanent, inactionable harm caused at the level of the epigenome, others invoked a contrasting narrative of flexibility and plasticity. Victoria promoted a narrative of rectification, advocating for the individual's agency to write past wrongs and the potential to optimize action to effect positive change. The malleability of the "plastic brain" figured in this narrative, as proof of the possibility for remediation and opportunity.

> "*…The brain is plastic. You can always change it, you know, in a positive or wrong way, but it can be changed...There's also a lot of negativity about epigenetics. We forget...we can also do positive things. Life gives us the chance to change it again and to make it right.*" (**Table 2: 3.1.2**)

The notion of the plastic brain was used by this participant as a means to console or relieve other women's distress over the epigenetic inheritance of trauma, there was a concurrent notion that specific windows—"the early years"—of brain development are very important, demanding meticulous action for goals of reparation or enhancement. The correction of issues in the past is conditional upon one's actions as a mother.

> *"I read a lot and most of it has to do with neuroscience and the way the brain is shaped and how the early years are super important… Even though you don't have your dream birth or the best, pregnancy, the thing is that you can change it, you can…you have every day to make it better and every day to achieve a positive experience with your kids."* (**Table 2: 3.1.3**)

Beatriz, with a degree in biology, was conscious of the tensions and binds of rhetorical themes that emerge across epigenetic translations of science. She articulated her understanding of the multifactorial nature of epigenetic impact: the complex interaction of risk and protective factors. Beatriz shared that even though her background and training afforded what she believed was a sophisticated ability to unpack and critically analyse scientific findings, she nonetheless found herself affected by headlines and various translations of biomedical research, her scientific acuity fading out of focus as she became absorbed with the popular medical discourse as a mother-to-be.

> *"They take a scientific paper, they take one piece of information, they make it a big headline. And then they talk about it like it was the end of your life. Your child is going to be an abuser or is going to be a rapist because your grandfather was. It's like, it's they take it out of context and it creates so much anxiety. And it's like, no, you know, it's such a small thing. The body has so many protection mechanisms. That it's not because something happened in the past, they're doomed to happen again. So balancing that perspective with being in the middle of the feeling and receiving all that information, you know, it's kind of hard for me and I kind of forgot about my theory, forgot about what I knew. I forgot about the deeper analyses and inside me I was like, Oh my God. And I had to remind myself, no, I dyed my hair, but my baby is going to be fine. And my grandmother killed herself when she was 40, but I'm going to be fine. My baby's going to be fine. It's a lot of work. I find that it's a lot. It's intense."* (**Table 2: 3.1.4**)

The translation environment of click-bait headlines, sensationalized scientific findings, and the dichotomy of simultaneous fatalistic and responsibilizing language was a source of anxiety, and she has to do the "work" to make sense of it and act accordingly.

Responsibilization of the Mother-To-Be

In their examination of the political and practical implications of epigenetic science, Wastell and White (2017) evoke Schrödinger to illustrate the tensions the epigenetic narrative poses:

> "In freeing us from determinism, this form of genetics creates a space for benignant social engineering. Schrödinger refers to its possibilities as 'beautiful, elating, encouraging and invigorating' (p107), but these enticing prospects may also create minatory moral hazards." (Wastell and White, 2017, p. 20)

Wastell and White (2017, p. 20) argue that "good enough parenting" (19) is no longer good enough in a context where a mother's behaviors, actions, and emotions are "etched indelibly on the infant's brain and written into the molecular activities of

its cells" (19). The epigenetic narrative places the responsibility on the mother to prevent damage to her infant via (a false notion of) control of micro and macro aspects of herself and her environment, and thus the mother becomes both an object of her own self-monitoring and an object to be controlled socially and biomedically. She holds the responsibility to protect her child from trauma or other nefarious influences such as her own behavior, her diet, and her mental health. There are numerous instances of this "with great power comes great responsibility" perspective circulating in the popular sphere. *"You can positively influence your epigenome,"* a slide in a TEDx video "Epigenetics and the influence of our genes | Courtney Griffins|TEDxOU" that has been viewed over half a million times (TEDx Talks, 2012) reflects this perspective: it is within a woman's power to do right (or wrong) and thus she is measured in the efficacy in which she promotes beneficial outcomes for her child. The manifestation of this denouement affords a context of monitoring by self or state.

> *"It made me angry at our society. This is ridiculous. It's like we have information telling us that having elevated cortisol levels and super high stress is absolutely associated with negative outcomes. But, there's no support for you...But, keep going and eat a fucking salad."* (**Table 2: 3.2.1**)

Women find themselves in numerous binds vis à vis their biomedical information consumption during the perinatal period. Our interlocuteurs reported the desire to self-educate to be informed and equipped with expert knowledge. Though participants sought the outputs of emergent biomedical and scientific research, they struggled with the navigation of its translations—itself a unsettling affair—and found their interaction cognitively and affectively straining. In response to these often lose-lose engagements with biomedical and cultural constructions of the perinatal period, some women found themselves stressed, others all together disengaged, but others acknowledged interpreting the narratives communicated to them in a flexible manner: "*I use it to my benefit when it works out, like a horoscope. When it doesn't work out, I don't like it*" (**Table 2: 1.1.3**)

Overall, participants felt that the outputs of current scientific inquiry into female reproduction—particularly from neuroscience or epigenetics—placed enormous pressure on them as individuals to affect change or control variables in their lives with oftentimes limited societal support. One participant, Teresa, actively refrained from engaging with the Internet during her pregnancy upon the realization that the pressure of responsibilizing messaging across biomedical research translations was creating distress for her.

> *"I think that there was some part of me that was very stubborn about resisting that kind of information because I felt like that it wasn't something that I should have to take on: that I should have to be worrying about every single thing I thought or felt or did. And so there was some part of me that was very rebellious that way. And then every once and a while I would get sucked in and it would cause me this terrible anxiety and I would have to go back and sit and think about what do I want, how do I feel?"* (**Table 2: 3.2.2**)

Teresa describes herself as being "rebellious" for avoiding engagement with biomedical research translations online. This notion of "rebellion" implies an authority to which she is expected to obey or expectations of norms or rules that she rejects. The preeminence of medicalized discourse around pregnancy and the availability and accessibility of medical and scientific expert knowledge has been shown to beget an internalized responsibility to self-educate (Marshall and Woollett, 2016; Tiidenberg and Baym, 2017). Teresa seems to be rebelling against the reach of authoritative science into her pregnancy experience. She seems to be resisting the expectation that it is her duty, responsibility to follow emerging research findings and current evidence-based recommendations. Women experience individual responsibilization to be informed and to act upon said information, whether it regard the mitigation of self- or externally-imposed expectations of mombrain-related incompetence, the necessitation of risk management and prevention of epigenetic insult through self-monitoring, the management of mental health, or micro scrutiny of behavior, actions, emotions, exposures, consumptions, etc. The web of various actors, vectors, and recipients of biomedical and pop culture pregnancy discourse has assisted in the creation of a climate where women are monitored by self and other.

> *"The other frustration for me which is less personal, it's more social, was this information should be used to make structural changes to lessen stressors on people's lives… We seem to have this idea that regardless of the science whether it's positive things you can do or negative things you shouldn't do, it still places enormous expectation on individuals."* (**Table 2: 3.2.3**)

DISCUSSION

Focused discussion revealed that many women find themselves trapped in a double bind with conflicting messaging and situated in various no-win situations when attempting to inform their choices as mothers and make sense of their perinatal experience.

A double bind (Bateson, 1972) is a situation of conflicting narratives or demands that the individual is unable to resolve or opt out of. The uptake of translations of neuroscientific findings on structural brain changes during the perinatal period has created such a bind for mothers: By accepting "pregnancy brain" as real, women compromise the perception of their competence. By dismissing pregnancy brain as not real, emotional, and cognitive challenges remain illegitimate, while women are faced with a social reality characterized by numerous demands, expectations, limited societal support, and inevitable exposure to social judgment as a pregnant woman and mother.

The experiences, emotions, and perspectives of our participants are reflective of the value and import of examining the dynamic life of a scientific discovery as it leaves the laboratory and is translated on entry to public spheres. Interconnected channels and feedback loops of the laboratory, science journalism, public opinion and reception, public and private funding bodies, influence broader "citation practices," and paths of research. With social networking and a plethora

of new media platforms, citations, or translations of research emerge in many forms across a diversity of channels.

Overall the media environment in which these women encounter biomedical perspectives and prescriptions around the perinatal period is a quagmire. Participants expressed a thirst for information during their pregnancies and into early stages of motherhood: having the information provides a sense of control and agency but oftentimes the information is equivocal and difficult to make sense of. Women encounter warnings of looming dangers to their children largely beyond their control while placing the onus on them as individuals without much scope of societal support.

Translation of epigenetic science thus introduces another bind. Offering leverage on the sticky predicaments and histories of your ancestors, it inflates the weight of this inheritance and puts one to work to undo what has been done without guarantee. Cognizant of this power to harm and to protect, the value of plasticity and choice afforded by this body of knowledge risks being lost to self-monitoring, responsibility and stress about stress.

Capturing a social anxiety around the impacts of the pandemic on infants and children, in May of 2020, the Canadian broadsheet newspaper, *The Globe and Mail* published an article entitled "Will pandemic babies live with the effects of their mothers' stress?" (Ungar and King, 2020). It is likely that the intensity, duration, and global scale of this event may heighten the attention of pregnant women to prenatal maternal stressors understood to compromise the developmental trajectories of their children via epigenetic and neurobiological pathways.

Future research should explore how the context of the COVID-19 pandemic is impacting on the actual experiences of women during the perinatal period, but also on the ways in which these experiences are being framed in terms of existing public health messaging drawn from biomedical research on the imprint of the environment on genes and the brain. The women whose narratives are the foundation of this paper shared their experiences and reflections across three focus groups held in late summer and fall of 2020. Months had elapsed since the COVID-19 pandemic first became front-and-center in life in North America. The wider realities of this context impacted the pragmatics such as recruitment process and focus group method, but also, and potentially the findings of this study. Earlier high-profile research initiatives such as the widely publicized "Project Ice Storm[3]" have reported that *in utero* exposure to prenatal maternal stress from an isolated independent stressor—in this case, the 1998 Quebec Ice Storm—resulted in significant long-term effects on "temperament, parent- and teacher-rated behavior problems, motor development, physical development, and IQ, attention, and language development," (Projet Verglas) the majority of which the research team purports persist past 19 years-of-age. The events of the 1998 Ice Storm left individuals without electricity for up to 45 days; at the time of writing, the COVID-19 pandemic has had profound impacts on numerous domains of life in North America for a year's time. How might women in diverse contexts be making sense of the length and gravity of this "event"?

In conjunction, new mothers may be concerned about the future behavioral development, such as compromised sociality, of their babies. Future research is needed to examine women's uptake, attitudes and feelings toward this specific area of COVID-19 related research, and the ways in which these interpretations are framed in terms of biomedical knowledge.

The women in our study were engaging with knowledge translations of the authoritative scientific bodies of epigenetics and neuroscience and applying these "imaginaries" (Meloni and Testa, 2014) to their own trajectories, experiences, and life predicaments. These translations are not innocuous. If a woman's expectations include that she will manifest inevitable mombrain-related incompetence or the prior that her level of stress puts her at high risk of harming her child's development, or the presupposition that she will develop postpartum depression from pregnancy-related changes in her brain—to what degree does the shaping of mindset and expectation by these presiding biomedical and cultural rhetorics engender the maladaptive changes in subjective experience, behavior, and physiology that are so feared?

The hope of objectifying certain phenomenological experiences and states biological proof continues to reignite rather than rid the tropes of earlier bodies of knowledge that stigmatized and responsibilized women, mothers, and the female body as such has clearly failed. Instead of liberating mothers, patients and others from this sense of moral or behavioral failures by providing corporeal difference and material validation, the notion that the brain is aberrant and the moral imperative to act on the body, though framed as agency for some, clearly replicates aspects of this historical stigmatization and responsibilization. Such responsibilizing narratives resonate with the notion of "mommy economicus" (Thornton, 2014), "a new mutation of the socially prescribed 'good mother'" offered up by "mombrain" brain discourses that stem from research on neuroplasticity. The maternal brain as a "kind" of brain has not only conjured maternal brain-related vulnerabilities or deficits such as "mombrain"-related-amnesia, but has also engendered dichotomous messaging speaking to maternal brain-based superpowers afforded by the unique window of maternal neuroplasticity (Thornton, 2014). "Mommy economicus" casts further light on this tension between the dichotomized rhetorics of both neuroplasticity and epigenetics: a sense of fixedness or determinism—not so different than implications of genetics—or a privileging of personal empowerment, individual choice, and self-fashioning characteristic of neoliberalism and postfeminism (Gill, 2007; Vavrus, 2007; Ehrenberg, 2011; Gill and Scharff, 2013; Thornton, 2014).

Our participants' engagement with brain science was positioned between a search for determinism to legitimize their challenges and the moral burden of choice. Their accounts demonstrate how neurobiological and epigenetic knowledge contribute to a particular "regime of truth," one in which—through molecularization of pregnancy and child development—a typical passage of life becomes saturated with "susceptibility," "risk," and the imperative to preemptively

[3]*Project Ice Storm Projet Verglas*. Available online at: https://www.mcgill.ca/projetverglas/icestorm (accessed February 25, 2021).

make "healthy" choices, in turn redefining and shaping the experience of what it is to be a "good," "healthy," or "responsible" mother/to-be. The illusion of agency conferred by shaping brains or imprinting DNA is continually shadowed by a sense of failure, disappointment, and vicious cycles of anxiety.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Institutional Review Board of McGill University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ION-S aided in conceptualization of the study, lead data collection and analysis, drafted the manuscript, contributed to conceptual work and editing of manuscript. AG-C was involved in intellectual conception, helped with interpretation of data, contributed to drafting, revising, and editing the manuscript critically. SC conceived of the study design, aided data collection, and made contributions to conceptual work and editing of the manuscript. All authors contributed to the article and approved the submitted version.

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TechnoBrainBodies-in-Cultures: An Intersectional Case

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The cyborgization of brainbodies with computer hardware and software today ranges in scope from the realization of Brain–Computer Interfaces (BCIs) to visions of mind upload to silicon, the latter being targeted toward a transhuman future. Refining posthumanist concepts to formulate a posthuman*ities* perspective, and contrasting those approaches with transhumanist trajectories, I explore the intersectional dimension of realizations and visions of neuro-technological developments, which I name TechnoBrainBodies-in-Cultures. In an intersectional analysis, I investigate the embedding and legitimation of transhumanist visions brought about by neuroscientific research and neuro-technological development based on a concept of modern neurobiological determinism. The conjoined trajectories of BCI research and development and transhumanist visions perpetuate the inscription of intersectional norms, with the concomitant danger of producing discriminatory effects. This culminates in normative capacity being seen as a conflation of the abled, successful, white masculinized techno-brain with competition. My deeper analysis, however, also enables displacements within recent BCI research and development to be characterized: from ‘‘thought-translation" to affective conditioning and from controllability to obstinacy within the BCI, going so far as to open the closed loop. These realizations challenge notions about the BCI's actor status and agency and foster questions about shifts in the corresponding subject–object relations. Based on these analyses, I look at the effects of neuro-technological and transhumanist governmentality on the question of whose lives are to be improved and whose lives should be excluded from these developments. Within the framework of political feminist materialisms, I combine the concept of posthuman*ities* with my concept of TechnoBrainBodies-in-Cultures to envision and discuss a material-discursive strategy, encompassing dimensions of affect, sociality, resistance, compassion, cultural diversity, ethnic diversity, multiple sexes/sexualities, aging, dis/abilities—in short, all of this "intersectional stuff"—as well as obstinate techno-brain agencies and contumacies foreseen in these cyborgian futures.

Keywords: intersectionality, neuroscience, neuro-technologies, transhumanism, neuro-governmentality, posthuman*ities*

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INTRODUCTION

In a recent documentary entitled "Myth of the Artificial Brain" (Denjean, 2017)[1], the French/German Television *ARTE France* channel presented an up-to-date account of the state of neuroscientific research and neuro-technological development, *as well as* outlining current visions of transhumanism. Human enhancement with the help of the latest scientific and technological advancements shall render more-than-human capabilities and intelligence possible, culminating in the possibility of mind upload to silicon. This is a new scenario. There are numerous popular science documentaries available covering current findings in neuroscience, including the development of Brain–Computer and Brain–Machine Interfaces (BCI/BMI) for improved treatment of patients suffering from communicative or motor impairment. There are also reams of fictional stories and films about artificial humanoids or humanoid robots. Furthermore, the transhumanist movement has disseminated its objectives (*The Transhumanist Declaration,* Various, 2013) worldwide via its internet appearances, e.g., the transhumanist party (www.transhumanist-party.org), Humanity+ (humanityplus.org), Extropianism (http://www.extropy.org/, an institute founded by Max More and Natasha Vita-More), Democratic Transhumanism (Hughes, 2004), or Singularity (Kurzweil, 2005). However, although transhumanists refer back to neuroscience and neuro-technologies, for decades, they have mostly been regarded as crackpots by established members of the neuroscientific research and neuro-technological development fields. Nevertheless, over the last few years, a new reciprocal connectivity has emerged: protagonists from both sides—the neurosciences/neuro-technologies and transhumanism—mutually refer to each other's findings, developments, and visions with a positive couleur, in particular just those interconnections popularized by the ARTE documentary. Neuroscientists predict that it will become possible to measure all functions of the brain and to explain human behavior and thinking as a whole in the near future. BCI developers connect brains with computer hardware and software for "thought" translation. A group of (neuro-)clinicians, (neuro-)engineers, computer experts, and transhumanists recently published a prognosticated Human Brain/Cloud Interface in *Frontiers in Neuroscience*, which would allow a person to get direct access to "virtually any facet of cumulative human knowledge" (Martins et al., 2019). Researchers of cryonics prophesy cryopreservation as a promising way of preserving enough brain information to permit future revival of cryopreserved persons and enable their human mind to be uploaded to silicon. In the ARTE documentary, we learn about Ken Hayworth, researcher at the Howard Hughes Medical Institute's Janelia Farm Research Campus in Ashburn, Virginia, a leading research institution in the field of connectomics[2], who has founded the Brain Preservation Foundation[3] with the aim of having his (sic!) brain cryopreserved after his death. After 100 years, it should be defrosted again and uploaded to silicon—as a "mind up," so he says! Moreover, the Brain Preservation Foundation awarded a prize to a laboratory for its first cryopreservation and later defrosting of a rabbit. These examples give an impression, I would suggest, of how science–transhumanist exchange is becoming intelligible in the sense of a discursive norm (Butler, 1990).

Nothing new: the ARTE documentary presented a significant number of *white*, successful, middle-aged men, who expounded on their research and visions, from visualizing the brain's connectome to the development of neuro-technologies, along with their visions of mind upload into supercomputers or robotic counterparts. No women appeared in the documentary within this group of leading representatives of the field, apart from two staff members and a female technician, who were shown conducting some experiments. Nor do any Non-whites appear, except for Hiroshi Ishiguru, who has developed the android "Geminoid" as his robotic twin. In actual fact, that is not quite true. Transwoman Martine Rothblatt is presented as one of the richest women in the world, complete with BINA48 (Breakthrough Intelligence via Neural Architecture 48*), a robotic head-like chatbot in which she has stored all memories of her black female partner Bina. An admittedly non-systematic search through my literature sample in the field of BCI/BMI developments revealed three women among 32 first authors in empirical studies. In contrast, in May 2020, the international NeuroGenderings expert network[4] embraced 88 members, 6 of them men—as far as I could assign their gender. The network connects scholars from a broad range of brain research disciplines, including neuroscience, neuropsychology, cognitive neuroscience, and epidemiology, with scholars from gender and queer studies, feminist science studies, and science and technology studies, all of them working in or about brain research. This is an interesting contrast. One could argue that the more brain science is conducted in a technical milieu, as in neuro-technology, the more men/fewer women are involved. In this paper, I will not be addressing the perspective of women in neuroscientific research or neuro-technological development, but I was struck by the lack of females and Non-whites[5] in the ARTE documentary. One might suspect that underlying gendered and racist concepts of the field invite or deter researchers in line with their suitability with regard to its objectives. Instead, I will focus on the neoliberal and colonial embeddedness of transhumanist visions, that, as Francesca Ferrando argues, is targeted at particular (upper) classes with economic power and consequently encodes racial and sexual politics (Ferrando, 2013, p. 27). Moreover, transhumanist visions and developments "realize the

[1]I have taken the ARTE documentary as a starting point and as a counterfoil throughout this paper, because it is one of the most recent documentaries in this sphere, along with others, and even more because ARTE is a TV station that is known for its critical features on science–societal relations and impacts.

[2]This field in brain science researches the overall network of fibers and connections within the brain: the connectome.

[3]https://www.brainpreservation.org/ (accessed January 6, 2021); the website also calls for donations, and in the ARTE documentary, it is told that Hayworth himself has already invested more than 1 million dollars in cryopreservation techniques and in the development of supercomputers to save (his) brain data.

[4]https://neurogenderings.wordpress.com/ (accessed January 6, 2021).

[5]This does not hold for the transhumanist movements whose internet presentations are more diverse with respect to gender and ethnicity of its members.

disembodied human self of the Enlightenment, purified and enhanced by science, medicine, and technology [. . .] a super-human dream of perfection as an infinitude that harbors a disregard of vulnerability" (Åsberg and Nematidis, 2013). In the ARTE documentary, Miguel Nicolelis, a leading developer of neuro-technologies, described the field as a European, US, and Japanese endeavor, thus placing it within the framework of North-Western dominance. He neglected to mention any other part of the world.

The two aspects of the documentary, i.e., the "new" intelligible connection between neuroscience/neuro-technologies *and* transhumanist visions along with the intersected ascriptions within these fields of research, developments, and visions, are the topics of my paper. My research has already addressed the impacts of gendered concepts within neuroscience and neuro-technologies, their grounding in Western neoliberal socio-cultures and, vice versa, their contribution to the persistence of powerful gendered hierarchies and discriminations (Schmitz, 2012, 2016, 2017). I will augment my analyses in this paper by looking through an *intersectional lens at the gendered and racist notions which frame BCI research and development, culminating in visons of brain emulation, and at what outcomes are intended for whom*. In particular, I will examine the prominent focus on the enhancement of a masculinized, *white* rationality and efficiency, while ignoring a feminized, uncivilized emotionality, drawing on the long herstory of Feminist Science Studies and the latest concepts of Postcolonial Feminist Science Technology Studies (for in-depth analyses, see Pollock and Subramaniam, 2017; Subramaniam and Willey, 2017; Subramaniam et al., 2017). The last of these uncovers the sexist and racist concepts of rationality and civilization vs. emotionality and uncivilized *otherness* as a product of Enlightenment in coalition with colonial politics. Another revelation from the ARTE documentary was that I have "encountered" most of the neuro-protagonists during my research on BCI developments over the last 15 years. This clearly raises questions about the mutual roots of this (re-)union. My second focus of the paper, therefore, aims to *identify the roots within neuroscientific research and neuro-technological developments that may lead to legitimization of transhumanist visions*. However, in both analyses, I will also *search for the inconsistencies and ruptures* that contradict the straight lines of intersected ascriptions contributing to discriminatory outcomes. How does (feminized) affect as compared to (masculinized) rationality come into play in neuro-technologies and transhumanist visions? What kind of obstinacy characterizes the BCI and what "trickster" (Haraway, 1992) qualities thwart the *white* neoliberal story of ultra(trans)humanism? With this approach, my third aim is to challenge the intersectional taming of neuro-technological realizations and transhumanist visions to *formulate a concept of neuro-posthumanities* that could be realized *in other ways* than by targeting heteronormative and intersectional "-isms."

Before starting this analysis, I will briefly describe my standpoint to the field of BCI-to-transhumanist visions. Fascination and apprehension accompany the development of brain technologies from Brain–Computer Interfaces (BCIs[6], for the enabling of impaired patients) to Brain-to-Brain Interfaces (BTBIs, fostering direct communication between brains). On the one hand, neuro-technologies can and should help humans in the case of illness or disease: for facilitating communication with ALS patients (amyotrophic lateral sclerosis, a neuronal disease in which a patient progressively loses muscle control and thus the ability to communicate), for the rehabilitation of mobility after a stroke or provision of neuro-prostheses, or for regulating symptoms of Parkinson disease using deep brain implants. On the other hand, these developments also provoke fears, ranging from possible uncontrollable effects on body, mind, or surroundings, ethical aspects of ownership, and the risk of neuro-prostheses injuring self or others. Furthermore, these ambivalences increase when it comes to debates about the potential of superseding "human nature" with neuro-technologies in transhumanist visions (Schmitz, 2017). My own ambivalence concerning neuro-technological phenomena is *not* about their possible realizations going beyond human "nature." If technologized brainbodies materialize through continuous intra-actions, and if they constitute and constantly re-constitute in science, technology, and society, these cyborgs, as Haraway (1985) has argued, may bear the potential to disrupt the modern dichotomy between feminized nature and masculinized culture (with technology seen as part of culture). As such, TechnoBrainBodies-in-Cultures (as I call them) could make reductionist biological determinisms obsolete, particularly those of rationalized masculinity vs. affective femineity that are used again and again to legitimize gendered and intersected lines of difference, social orders, and norms. However, the cyborg metaphor is ambiguous, oscillating between the potential of imploding binary orders on the one hand and the horror of control and exploitation on the other. Haraway, in most of her *Cyborg Manifesto*, has already emphasized the powerful practice of domination through informatics that legitimizes intersectional inclusions and exclusions from citizenship (Haraway, 1985).

My understanding of TechnoBrainBodies-in-Cultures is based on politically framed feminist materialisms as onto-epistemological phenomena, embedded in time–space undergoing a process of constant change. I employ Karen Barad's agential realism (Barad, 2003, 2007) as an analytical perspective to consider the agential forces of matter, technologies, and creation of meaning in BCI. I understand the notion of agency as an enactment that is not necessarily bound to consciousness or intentionality, attributes that are commonly aligned to human subjectivity. Agency in this sense

> "*is the enactment of iterative changes to particular practices—iterative reconfigurings of topological manifolds of spacetimematter relations—through the dynamics of intra-activity. Agency is about changing possibilities of change entailed in reconfiguring material-discursive apparatuses of bodily production, including the boundary articulations and exclusions that are marked by those practices in*

[6]In the following, I subsume Brain-Computer Interfaces and neuro-prostheses, the latter often termed as Brain–Machine Interfaces (BMI) under the one term of BCI.

> *the enactment of a causal structure" (Barad, 2007, p. 178, italics taken from the original).*

Diana Coole's concept of politically framed materialisms complements my theoretical framework,

> "in order to understand its materialization and, from a critical perspective, the way it is entangled with power relations, it must attend to the microscopic and macroscopic, the molecular and the molar. This means tracing politico-economic, geopolitical and biophysical circuits, conduits and networks through which matter passes as it is transformed, given surplus value, degraded, rerouted, hoarded and so on" (Coole, 2013, p. 464).

From the perspective of political feminist materialisms, the field of Brain(Human)–Computer (Techno)–Intra-actions touches on a range of questions concerning the agencies within these phenomena, the transgressions of subject–object and culture–nature boundaries through their realizations, their impact within bio-techno-socio-cultural entanglement, as well as their intersectional taming.

My following analysis will be undertaken in three steps. *First*, I will enroll the visions of transhumanism which "aim[s] to uphold the energy and political might of millions of transhumanist advocates out there who desire to use science and technology to significantly improve their lives"[7]. This agenda obviously raises the question of whose brains and lives should be improved and whose should be excluded from its visions (Hughes et al., 2016). Competition turns out to be defined as the normative capacity for the visions of uploading the mind to silicon: "[c]ompetition is an inescapable occurrence in the animate and even in the inanimate universe. To give our minds the flexibility to transfer and to operate in different substrates bestows upon our species the most important competitive advantage[8]." I will take up some of the underlying concepts of transhumanist visions and work out the depth of their framing by intersectional hierarchized categorizations in terms of what should be technologically enhanced in what ways, by whom and for whom. I will not analyze the whole framework of transhumanist singularities (for details of the multiple fields, see Ferrando, 2019, p. 29–38; Gladden, 2018) but focus on those lines of arguments that intersect with recent brain science and neuro-technological developments, particularly when improvements shift "closer to transhumanist-impelled ideas in the field of neuroscientific brain research that focus rather on enhancement than on treatment" (Stollfuß, 2014, p. 92). According to my particular perspective, it would be important for these facets to be disclosed when it comes to the framing of TechnoBrainBodies-in-Cultures for a neoliberal, *white* masculinized effective North-Western society.

In a second step, I will question how the concepts of BCI developments frame the discourses on mind upload in transhumanist visions—or vice versa, how the latter frame the former. Over the past decade, there have been some analyses of transhumanist trajectories (e.g., Sharon, 2012; Ferrando, 2019), of how neuroscience and transhumanism interact (e.g., Stollfuß, 2014)[9], and of intersected inscriptions in transhumanism (e.g., Åsberg and Braidotti, 2018). However, there is a dearth of analysis about how gendered and intersected inscriptions are embedded in neuro-theories and BCI developments and how they are taken to legitimize visions of enhanced artificial brains or ultra-humans. I will ask how neuro-technological developments strengthen or transgress gendered and racialized intersectional inscriptions, whereby masculinized thought and rationality is the to-be-enhanced vs. feminized emotions and unconsciousness is the to-be-avoided. Particularly, I aim to search for fractures that could lead to the inclusion of *otherness* and thus to alternative perceptions of TechnoBrainBodies-in-Cultures.

In a *third* step, I outline the current embedding of neuro-technological developments within a normative neuro-governmentality of enhancement. Based on my previous analyses, I will challenge the term "transhumanism" by contrasting it with the term "posthuman*ities*," for which I am indebted to Cecilia Åsberg and the Posthumanities Hub; this is an approach that aims to question the more-than-human condition with the help of inventive feminist materialist philosophies. I aim to question how neuro-posthuman*ities* could be realized *in other ways* than by targeting heteronormative and intersectional "-isms" (as in transhumanism). Thus, I hope to develop strategies to integrate into cyborgian developments of TechnoBrainBodies-in-Cultures all the "disturbing intersectional stuff" of affect, sociality, aging and dis/abilities, uncontrollable bodily agencies, as well as obstinate agencies and contumacies. This will be not only an analysis but also a feminist intersectional future perspective.

The following analysis is not rectilinear. It will unfold in loops and sidetracks to uncover not only intersectional issues but also incongruities showing that these developments are not as easy and (pre)determined as expected, a journey through and with TechnoBrainBodies-in-Cultures that hopefully will open up other interpretations for posthuman*ities*.

TRANSHUMANIST VISIONS: BRAIN UPLOAD—WHOSE BRAINS, WHICH CAPACITIES?

I start with some clarification of terms, particularly those of posthumanism and transhumanism and the relations between the both. The main objective of the posthumanist agenda is to decenter the notion of the human in worldly phenomena. The term posthumanism, rooted in postmodernism and having evolved out of a philosophical, cultural, and critical agenda (Ferrando, 2019, p. 1), became prominent with the turn of the millennium and covers a two-fold approach: to acknowledge that the human's "imbrication in technical, medical, informatic, and

[7]http://www.zoltanistvan.com/TranshumanistParty.html (accessed January 3, 2021); Zoltan Istevan in one of the founders of the Transhumanist party, and its today's political and Media Advisor, see http://transhumanist-party.org/advisors/.
[8]http://www.scifuture.org/extending-life-is-not-enough/ (accessed December 27, 2020).

[9]Sven Stollfuß analyses the EU Human Brain Project "in order to emphasize the rise of the posthuman brain on the backwash of visions between treatment and enhancement" (Stollfuß, 2014, p. 82).

economic networks is increasingly impossible to ignore" (Wolfe, 2009, p. xvi) and, at the same time, to unfold the impacts and effects of this biotechnological and techno-cultural entanglement on human concepts and identities.

In contrast, transhumanism is characterized as targeting "the enhancement of 'human nature' with the help of advanced technologies such as nanotechnology, biotechnology, robotics and information and communications technology" (Stollfuß, 2014, p. 83). As such, it can be separated from the critical stance of posthumanism in view of its techno-reductionism as "a hierarchical project, based on rational thought, driven toward progression" (Ferrando, 2013, p. 28). While undoubtedly, posthumanist scholars have distanced themselves from the transhumanist visions of downloading or uploading the human mind to artificial hardware, there is a danger in today's reception of both terms. Post- and transhumanism, respectively, become mixed up and either term may be used solely to describe the enhancement endeavor targeting the more-than-human entities, particularly within the "populist strand of posthumanism" (Ginn, 2017, p. 3). To face this problem, Åsberg (2013) proposed a change in the terminology to the notion of posthuman*ities*, aiming at taking up the decentering prospect of posthumanism while sharpening its separation from transhumanism.

However, to provide a short impression of the critical posthumanist-to-posthuman*ities* agenda, I will outline a short herstory by following the conceptualization of the posthumanist perspective with focus on its particular facets regarding my paper. I start with Katherine Hayles' seminal book *How We Became Posthuman (1999)* in that she claims that posthumanism

> "embraces the possibilities of information technologies without being seduced by fantasies of unlimited power and disembodied immortality, that recognizes and celebrates finitude as a condition of human being, and that understands human life is embedded in a material world of great complexity, one on which we depend for our continued survival." (Hayles, 1999, p. 5)

Hayles, as well as other authors, revises the critical posthumanist approach to Haraway's Cyborg vision (1985), with the cyborgian concept of bio-techno entanglements as fact and fiction. Cyborgian realizations are already part of our world and the cyborgian concept holds out a vision of transgressing gendered binaries of nature vs. culture. The latter could potentially prepare the ground for naturecultures (Haraway, 2003) that might dissolve powerful intersected categorizations and discriminations. Haraway's feminist posthumanist approach has been taken up within feminist materialisms as a prolongation of feminist poststructuralism (Butler, 1990), meanwhile acknowledging the material–discursive entanglements within the becomings (Haraway, 2008) of worldly phenomena. Onto-epistemological analyses of scientific knowledge production and of bio-technological developments—all embedded in, impacted by, and affecting socio-cultural power relations—could lead, according to Barad (2007), to posthumanist performativity. These approaches have drawn a clear connection between posthumanist critiques and degendering objectives, as implemented by Rosi Braidotty in *The Posthuman* with her call for a decline "of secular scientific rationality allegedly aimed at the perfectibility of 'Man'" (Braidotty, 2013, p. 37). Of importance for the focus of my paper is the intersectional lens of posthumanism that Josef Barla perfectly elucidates in an abstract for a seminar:

> "Contesting the very dichotomy of culture and nature, 'we' and 'them', humans and nonhumans, feminist and postcolonial scholars emphasized the existential need for decentering and deconstructing the anthropocentrism, essentialism, and universalism inherent to Enlightenment humanism. Shifting the focus to the marginalized and marked—that is, to 'all constituted as others, whose task is to mirror the self', as Donna Haraway put it—posthumanist theories aim for novel critical figures and tropes in a world thoroughly transformed by technobiopower and the technosciences. At the same time, transhumanism gains a foothold as a kind of technophilic hyper-humanism that seeks to take control over human evolution itself through the means of existing and hypothetical future technologies such as cognition enhancing drugs, nanotechnologies, cryotechnologies, and whole brain emulation." (Barla, 2019)

I agree with these trajectories. Responding to the aspiration "toward elaborating alternative ways of conceptualizing the human subject" (Braidotty, 2013, p. 37) and developing modes for "continued survival" (Hayles, 1999, p. 5) with cyborgian visions (Haraway, 1985), I appreciate the recent modification of the critical and intersectional term "posthumanism" to become "posthuman*ities*" (Åsberg and Braidotti, 2018; Braidotty, 2018). I will return to this perspective in the last step of my paper, but first I will focus on the relations between neuroscience, neuro-technologies, and the transhumanist discourse.

The second (EU-based) *Human Brain Project*, conceptualized 2013–2023[10], with a funding of 406 million Euros already up to 2020 (HBP Project Grant Structure, Web[11]), targets in the first instance at the improvement in the information exchange and networking between neuroscientific research groups and at sharing brain data with the help of neuroinformatics. Brain Simulation (i.e., the replication of brain architecture and activity on super-computers) appears as the second step in the HBP (Overview, Web)[12], introduced with the phrase: "Can you imagine a brain and its workings being replicated on a computer? That is what the Brain Simulation Platform (BSP) aims to do" (HBP Brain Simulation, Web[13]).

[10]https://www.humanbrainproject.eu/ (accessed December 26, 2020); the HBP connects more than 110 European and international research institutes and companies, e.g., CoreTec with Pascal Fries as member of its advising board, mentioned here because Fries is also chair of the Ernst Strüngmann Instituts (ESI) for Neuroscience in cooperation with Max Planck Society, Frankfurt, and he was a protagonist in the ARTE documentary (Denjean, 2017).

[11]Human Brain Project Grant Structure, https://www.humanbrainproject.eu/en/about/human-brain-project-ec-grants/ (accessed December 26, 2020).

[12]https://www.humanbrainproject.eu/en/about/overview/ (accessed December 26, 2020).

[13]https://www.humanbrainproject.eu/en/brain-simulation/ (accessed December 26, 2020).

The first HBP[14] was already based on the notion of the "cerebral subject" (Ortega and Vidal, 2007), the anthropological figure of the human, according to which all decisions and actions are explainable and predictable from the brain. The second HBP as well is presented as the endeavor to research and collect comprehensive knowledge of the brain to explain all thinking and behavior of the human subject. Sven Stollfuß showed how the new facets of the EU-HBP are related to information technologies to "define the computational principles of the functional and structural organization of the brain" (Stollfuß, 2014, p. 84) with the enhancement-based notion of an "ICT-accelerated "in silico cerebral subject"" (Stollfuß, 2014, p. 91, italics taken from the original. Moreover, the prospects of the HBP extend far beyond the cyborgian individual. Neuromorphic technologies are targeted to implement biological neural networks as analog or digital copies on electronic circuits as SpiNNaker and BrainScaleS architecture. These trajectories exhibit a double feature, combining visions of brain upload with the aim of improving computer technologies based on the model of the brain:

> "In the medium term we may expect neuromorphic technologies to deliver a range of applications more efficiently than conventional computers, for example to deliver speech and image recognition capabilities in smart phones. [. . .] In the long term there is the prospect of using neuromorphic technology to integrate energy-efficient intelligent cognitive functions into a wide range of consumer and business products, from driverless cars to domestic robots. [. . .] The fact that major companies like IBM have defined cognitive computing as their main business for the future makes the development of neuromorphic hardware architectures especially interesting and economically attractive." (HBP, Silicon Brains, Web[15])

These trajectories demonstrate even more strongly: the embedding of the "*in silico* cerebral subject" within neoliberal governance of enhancement, as well as the formation and perpetuation of those social structures based on the paradigm of neoliberal economic growth in particular.

A very controversial discussion within the heart of the European neuroscientific community frames the scientific policies in handling this project[16]. There have been various critical analyses of the "new" neuroscience conceptualizations (e.g., Choudhury and Slaby, 2012) and of the relationships between neuroscience, neuro-technologies, and neuro-governmentality (Maasen and Sutter, 2007; Rose, 2012). However, here I will concentrate on the prospected line of creating the virtual brain, and even of perhaps making the individual brain immortal in digital worlds. Stollfuß (2014) has impressively investigated the amalgamating trajectories of the HBP with reference to the transhumanist prognosis. In a detailed analysis, he draws parallels between the HBP project lines for collecting all brain knowledge in multilevel brain models with the help of brain simulation and supercomputers along the developmental lines in transhumanist concepts: drawing on such brain databases, these lines target functional brain emulation to species generic brain emulation, i.e., the setup of generalized brain surrogates in silicon. Moreover, individual brain emulation comprises three possibilities of "Whole Brain Emulation": social role-fit emulation, mind emulation, and personal identity emulation, thus not only figuring out technological "thought" upload as seemingly personal decision but also fixing normative social roles and requested identity formations. Stollfuß adopts these transhumanist lines from some of the main protagonists in the transhumanist field, namely, Sandberg and Bostrom (2008), Koene (2013), and More and Vita-More (2013):

> "To push the vision further, in the 'century of the brain' the ICT-accelerated '*in silico* cerebral subject' in computational neuroscience—and particularly in the 'Human Brain Project'—can easily be synchronized with the requirements of its media technological environment. In this point of view, the 'Human Brain Project' moves closer to transhumanist-impelled ideas in the field of neuroscientific brain research that focus rather on enhancement than on treatment." (Stollfuß, 2014, p. 92/92)

As such, the transhumanist visions of a "radical transformation of the human condition by existing, emerging, and speculative technologies (as in the case of regenerative medicine, radical life extension, mind uploading, and cryonics)" (Ferrando, 2019, p. 3) are being debated. What is missing to date, however, is a profound analysis of the newest lines in BCI development concerning its intersectional inscriptions in relation to transhumanism. I have shown already the heteronormative framing of targets of rationality and consciousness that guide (self-)technologies of cyborgian brainbodies, for example, the permanency of masculinized rationality as the to-be-enhanced and feminized emotionality as being ignored (Schmitz, 2012, 2016). Can I find new challenges or also new possibilities when looking at the latest developments and discourse?

ROOTS AND RUPTURES IN NEUROSCIENCE AND NEURO-TECHNOLOGIES

First, a deeper probe of the concepts underlying neuro-technological developments and transhumanist visions is necessary. During the last decade, the imaging of brain's connectome has become the leading target at the heart of the new Human Brain Project to research and extract brain-based explanations of most human behavior. The leading slogan "We are our brains," explicated by Ortega and Vidal (2007) has turned into "We are our connectome," as Nicolelis phrased in

[14]The first HBP was funded by the US National Institutes of Health under the realm of the "Decade of the Brain" (1990–1999), proclaimed by George Bush. Its main objective was to sample brain data from the genetic up to the functional level of the brain, to develop tools for presenting brain data and for matching data between research groups (Koslow, 2000).

[15]https://www.humanbrainproject.eu/en/silicon-brains/ (accessed December 26, 2020).

[16]An Open Letter, signed by 156 "Principal Investigators/Directors, eligible for HBP funding" and addressing the European Commission was launched on July 7, 2014, on http://www.neurofuture.eu/ (a page that is not available anymore). Mostly scholars from cognitive neuroscience complained not only about the exclusive funding politics of the HPB but also about its plan to map the entire human brain in computer models (Editorial, 2014).

the ARTE documentary. Moreover, the connectome is taken as an epistemic object (Rheinberger, 1997) to predict a future in which neuroscientific research will even be able to measure "thoughts," anticipating a future-oriented ability to capture thoughts through technology.

At the same time, the development of brain structure, physiological processes, and activation networks turns out to be embedded in a constructive process operating between nature and culture. In principle, the plasticity concept can help to explain inter-individual diversity as well as intra-individual variability. Based on the concept of entanglement (Rippon et al., 2014), plasticity deconstructs essentialist and binary ascriptions to a sexed brain. However, the idea of plasticity and modifiability of the brain can go hand-in-hand with the "modern neurobiological determinism" (Schmitz, 2012, p. 262). This notion is used to predict human thinking and action from brain data at the time of measuring, independently of the emergent bio-socio-cultural plasticity. In consequence, the brainbody is still framed as the essential entity, as the origin and cause of behavior, cognition, and decision-making. I termed this neurobiological determinism "modern" in the true sense of the enduring Cartesian dualism (of nature vs. culture) with all its associated sexisms, racisms, etc. I have also shown that modern neurobiological determinism does not contradict trajectories of modification of the underlying neuro-materiality, but is almost always conducted in a controllable manner. Moreover, narratives in a neo-capitalist society have a tendency to align the brain's plastic capacity to the corresponding ideal of an adaptive and flexible subject (Schmitz, 2012, p. 262).

Meanwhile, brain images, brain imaginaries, and the concept of brain plasticity form the core of developments in new lines of neuro-technologies. Furthermore, transhumanist imaginaries of mind upload are legitimated by and depend on this view of biomatter-based full coverage of thinking and acting. The narrative of the brain connectome is also the starting point of the ARTE documentary (Denjean, 2017) as the most promising resource for upcoming future technologies enabling brain upload. The aforementioned Ken Hayworth argues that the brain is a program covering our identity (even our soul as he terms it), with our experiences saved in the brain's connections. Note that this model comprises within its neuro-determinist concept the bio-social becoming of the brain.

However, the brain's complexity (particularly that of the human, but even that of animal brains) enables processes of cognitive abstraction ("thoughts") beyond neuro-materialism. Abstraction has neuronal correlates, but abstraction cannot be traced back to its origins in neuronal or connectome materiality, and respective neuronal activity alone. The brain's capacity derives from passing a threshold of complexity to achieve a more-than-material emergence. Emergence, as I learned back in the 1980s from my neurobiological mentor, does not mean something mystical. Emergence is a qualitative outcome of high complexity *per se*. Elisabeth Wilson in 1998 already referred to this aspect in her book *Neural Geographies*, where she elucidated the concepts of neuro-constructivism, stating that "figure cognitive processing as the spread of activation across a network of interconnected, neuron-like units" and "individual units have no representational status as such, it is the overall pattern of activity across the network in total [that counts]" (Wilson, 1998, p. 156). If, in principle, one is dubious about the possibility of a complete mind upload to silicon in view of its inherent more-than-material quality, this points to uncertainties about the explanatory value of neuroscience and poses questions about uncontrollable obstinacies within neuro-technological developments. As Alaimo (2014) states, these uncertainties and obstinacies challenge notions about the meaning of human subjectivity within transhumanist visions of mind upload, to say the least. This also calls for a speculative turn within the debates about feminist materialist performativity (Åsberg et al., 2015) and, in my view, calls for the opening up of the feminist materialist debate concerning the neurosciences and transhumanism to an integration of moments of fluidity, intersectional facets, and postcolonial movements.

I have analyzed BCI developments from around the turn of the millennium and in the first decade of the 20th century (Schmitz, 2012, 2016). In search of the foundations that lead to transhumanism, I will refer to these findings and proceed to focus on the relevant aspects of recent BCI research and development from the second half of the 2010s in order to search for intersectional issues that link various "-isms" such as rationalism, sexisms, racisms, emotionalism, controlism, and agentialism, with a particular focus on unforeseeable developments. In particular, this means tackling the frictions between rationality and affect (or better to say between thoughts and emotions), between controllability and obstinate BCI agencies, and to follow the material traces, actor's status, agency, and subject–object relations in closed and open neuro-technologies. All of these facets and their conceptions in BCI research and development are deeply intertwined. I am seeking to understand how they prepare the ground for the legitimation of intelligible targets in transhumanist visions, as well as how they are impacted by these visions. I search for their grounding in modern neurobiological determinism and for intersected norms and values that are inscribed therein, as well as for the fractures and discrepancies that may open up alternative views of a posthuman*ities* future. The following main protagonists all appear in the ARTE documentary (Denjean, 2017) connecting transhumanism with the latest neuroscience research and neuro-technological developments.

Unconsciousness and Affect in BCI

A short review of the herstory of BCIs. In 1999, Nils Birbaumer (first big name in the play) and his research group presented an ALS patient who learned to change his EEG waves to move a cursor up and down on a computer screen in order to select letters. The researchers called this BCI initially the *Thought-Translation Device*, and under this name, it was widely disseminated and referenced. It turned out, however, that the successful realization of this BCI communication was not simply based on conscious decisions made by the patient but required processes of operant conditioning[17]. With this, unconscious

[17]Conditioning is a learning procedure, the term derived from animal behavioral studies, that is based on the materialization of timely associated inputs into the brain. Classical conditioning sets an unconditioned stimulus (i.e., food) simultaneously with a conditioned stimulus (i.e., a bell) with the outcome of salivation solely to the bell. Operant conditioning takes practices to combine

facets also come to the fore and this unconsciousness is related to affective status. This most interesting aspect arises from the patient's "descriptions" with the help of the BCI system about his long-lasting efforts to produce a feeling of a "pressure in the brain" in order to select a letter or, alternatively, to "empty his thoughts" to achieve a letter rejection. This is how the PhD student, Nicola Neumann, who conducted the study, interpreted this practice:

> "… it was not the controllable production of his 'thoughts' (as a metaphor of the rational mind) but the inseparable entanglement with brain activities and even with sudden emotions that guided the communication process" (Neumann, 2001, p. 62).

However, this interpretation was at first only mentioned by psychology student Nicola Neumann in her thesis; in the subsequent publication by the whole Birbaumer group (Kübler et al., 2001), this focus on unconscious emotions instead of thought translation vanished when it came to presenting the findings from more patients.

Follow-up BCI developments addressed processes of conditioning to improve the communication between a brainbody and a computer, for example, to repair or replace damaged motoric brain areas in stroke patients. For my focus here, the newer developments that put affective stimulation into practice to develop even more effective BCI are worthy of note. Exhibiting a so-called *neuro-force feedback*, Silvoni et al. (2011) stimulated muscles of a paralyzed finger (unconditioned stimulus) and brain areas neighboring the stroke area (conditioned stimulus) to induce a plastic adoption of the finger's movement regulation by "new" brain areas. Castermans et al. (2014) operated a classical conditioning and combined muscle stimulation of a paralyzed limb with an activation of the motor cortex by a neuro-prothesis instead of conscious "thought" regulation. The transfer of the conditioning process into the BCI should "promote neuroplasticity in combination of traditional physiotherapy [bottom up] and robot-aided therapy [top down]" (Castermans et al., 2014, p. 34).

For completely locked-in patients, it is not clear whether they can understand a question if they cannot give an answer. De Massari et al. (2013) used classic conditioning to stimulate sensoric brain areas (unconditioned stimulus) simultaneously with questions and Yes/No answers about the name or mood (conditioned stimuli) of such patients. After 3 weeks of training, one patient showed some brain activation in response to the conditioned stimulus only. One might regard this as being only a marginal aspect of BCI development. Yet, the affective unconscious learning approaches were celebrated as a milestone in the further development of BCI to facilitate communication with completely locked-in patients (Chaudhadry et al., 2017). The Birbaumer group, in 2019, claimed that their studies would enable the examination of severely disabled patients in their domestic environment. These studies add value to mood-driven "communication," at least for health issues.

Returning to the question of thought translation as a committed prerequisite for brain upload: it is interesting that the popular media prioritized another aspect: "Could Birbaumer read thoughts?" was the question posed by the German newspaper *Süddeutsche Zeitung* (Bauer et al., 2019). Although the Birbaumer group denied that they had been able to read thoughts with their studies, using brain signals alone to move a cursor or recording brain reactions to Yes/No answers, it is interesting how connections between measurement and thought translation were immediately drawn[18].

In the past 2 years, however, emotion and mood-related recognition of communicative signals in the brain have gained more and more prominence in BCI research and development. The debate about the possibility of detecting "consciousness" in locked-in ALS patients or patients in vegetative state (VS) or minimal consciousness state (MCS) is gathering pace. Successful communication with three of eight patients in MCS has been reported with the help of EEG-based BCIs and by using movie clips of crying or laughing (Pan et al., 2018). The group released another publication in 2020, in which they reported an improvement of behavioral answers using an EEG-based BCI in 15 of 18 patients with cognitive motor dissociation (83.33%), whereas only 5 of 27 unresponsive wakefulness syndrome patients (18.52%) regained consciousness (Pan et al., 2020). Some BCI developers target EEG-based BCI as the technology of the future (Guger et al., 2017), while others are moving onto new technologies, e.g., time-resolved functional near-infrared spectroscopy (TR-fNIRS) based BCIs that detect the mean time-of-flight of photons to calculate the increase in blood oxygen levels in activated parts of the brain over time (Owen et al., 2006). The group of Adrian Owen was celebrated in 2020 for having extracted features of activity in the brain in 21 healthy subjects who "answered" a series of questions by imagining playing tennis for "yes" and staying relaxed for "no" (Abdalmalak et al., 2020). In this context, the efforts of the Owens group are interesting: to link non-purposeful imaginings (playing tennis) or mood reactions (staying relaxed) to consciousness is a similar project to the Birbaumer's group's first Thought Translation Device from 1999. Although this BCI has only been tested with healthy subjects up to now, it is prognosticated as an upcoming device for unconscious patients (Owen, 2020).

From an intersectional perspective, the acknowledgment of mood and affect as being important communicative facets sounds promising, alongside a vision of up-valuing these qualities of

conditioned stimuli (e.g., a keypress) with an unconditioned stimulus (e.g., food). In a series of trial and error, the animal learns to press the correct key to get the food award. Both learning procedures are accompanied with changings in the synaptic and neuronal connections in the brain, thus being defined as unconscious learning due to brain plasticity.

[18]It should be mentioned that this research has been subjected to critical examination in the last 2 years due to an evaluation by Reinhold Scherer, a BCI specialist of the University of Essex, U.K. He had found irregularities in the data analyses of the study and claimed: "Trials with locked-in patients are extremely expensive and logistically difficult, so it is hard for other groups to replicate the work. […] The hint that there might be a way to communicate with these patients is a welcome message, but there's just not enough evidence that we can definitely say it's working" (Vogel, 2019). These claims provoked a critical assessment of the studies of the Birbaumer group with completely locked-in patients subsidized by the German Funding Association (DFG) that led to the exclusion of Birbaumer and Chaudhadry from further funding due to scientific malpractice.

a more than solely rational mind. I argue that a focus on unconscious facets, mood, and affect could form the ground for a speculative turn on what could also be at stake in the development of neuro-technologies, besides the goal of thought translation and communicative enhancement. My approach draws a connection between decolonial and posthumanist agendas with respect to language, following Sousa and Pessoa (2019). This is a necessary backdrop for an informed discussion of the potential of up-valuing emotion within BCI development. In accordance with Mignolo (2018), Sousa and Pessoa criticize the dominance of seemingly unique principles of knowledge, challenging the concept of the operation of linguistic rules for maintaining homogeneity, normativity, and control in a Western agenda. Instead, they argue for recognizing decolonial concepts of language. This involves taking into account indigenous notions, e.g., of language connected to land, and elevating these to the same explanatory level as applied to knowledge. This decentralization would undermine the Western notion of lingual superiority. Sousa and Pessoa also point out that "[t]his colonial and humanist project focused on the idea of language taking place exclusively between human heads, and that entailed the disregard of people's bodies and senses" (Sousa and Pessoa, 2019, p. 531). Applying this approach to BCI communication, the valuing of emotions could decentralize the notion of (only) thoughts as the respected quality therein.

However, what becomes evident is a twist in the media narratives that turns mood-associated BCIs into a means of targeting the speaking capacities of the related (imagined) patients. I would argue that mood and affect, in these narratives, are not valued as qualities per se, but are only factors on the way to thought detection and rational conversation. The Owen group argues: "Basically, a brain-computer interface can read brain activity and find patterns for different words. In a way, the computer can speak for the person, only by connecting to the brain[19]," or "BCIs are devices that allow the brain to communicate with an external device that 'speaks' for them[20]." Furthermore, in the scientific sphere, these developments refer back to a long-lasting debate about identifying the neural correlates that would be minimally sufficient for consciousness (Owen and Guta, 2019). Additionally, several lines emerge from this research that lead to transhuman features and neoliberal governance of emotion: "emotions research has a wide range of benefits from improving learning outcomes and experience in Intelligent Tutoring System (ITS), as well as increasing operation and work productivity" write Xu et al. (2018). There is an increasing market for BCI emotion recognition systems[21] outside the health sector, most claiming to improve the individual management of work performance. Steffen Steinert and Orsolya Friedrich, in their paper on ethical issues of upcoming affective BCI, give an overview of devices that are able not only to detect but also to influence and stimulate affective states. "For example, emotional profile building could help to subtly emotionally influence people for economic or political gain. Due to the sensitive nature of data about mental states, issues of mental privacy, cognitive liberty and mental integrity have to be raised with stronger emphasis" (Steinert and Friedrich, 2020, p. 363).

Obstinacy in the Closed Loop

Miguel Nicolelis and Michael Lebedev (the second group of big names) have staked out the ground and claimed the territory in neuro-prosthesis development with their Macaques study. Again, a little herstory: Aurora (sic!), a young female macaque, learned to move a ball on a computer screen with a joystick into a cube. Along the way, a parallel control of a robotic arm was conducted with the same action. When the researchers removed the joystick, the ape decreased her arm and hand movements. However, the movement of the robotic arm continued. The authors concluded that the ape learned to operate the robotic arm solely by neuronal activity; by her thoughts, as they first framed it (Nicolelis, 2003). However, very soon, Lebedev and Nicolelis (2006) developed the term "closed loop." The ape needed multiple feedbacks during training, i.e., food reward and visual and sensory feedback, to learn a successful regulation of the prosthetic arm. As in the case of the ALS patient in the first Birbaumer study (Birbaumer et al., 1999), a visual feedback from the moving cursor on the computer screen was essential as a positive reinforcement to acquire the skill to lower or raise his cortical potentials. Thus, an effective development of BCI and neuro-prostheses depends on the learning plastic brain and learnable algorithms, which mutually frame each other *inside* the bio-techno materiality. The term closed loop has entered the field of neuro-technological developments and is used widely, but it is by no means banal.

I have shown (Schmitz, 2016) how, in the following years, the responsibility for the learning process and plastic reorganization within the brain was successively assigned to the technology. The legitimation for this handing over the signal responsibility to the technological agency was its higher efficiency in rehabilitation. Cunningham et al. (2011) did not themselves program the algorithms for neuro-prostheses but let them calibrate "*online*" with the brain to improve the algorithms for neuro-prosthetic control. Such an *Online Prosthesis Simulator* (OPS) proved to be more accurate without the intervention of the developers (for details, see Schmitz, 2017). Similarly, in a *functional electrical stimulation* (FES)-BCI (Soekadar et al., 2015), the conditioned stimulus that regulated a movement of a robotic finger was generated from the algorithms and not by the developers. Not only should the brain learn due to its plasticity, the software algorithms of the neuro-prosthesis too should adapt gradually to the brainbodies' rehabilitation process.

Nevertheless, with the closed loop, neuro-prosthetic development has been assigned a unique ontological status. The concept acknowledges a kind of obstinate agency within the BCI, in the sense of mutual learning and formative processes between the brain and the technology. I would speak of an *obstinate agency* within the closed loop that could offer unforeseeable phenomenal becomings. What could it mean when arm amputees learn impossible arm movements while observing an artificial arm and imagining "impossible" movements of the

[19]https://blog.despatch.com/new-brain-computer-interface-tech-will-soon-let-unconscious-patients-communicate/ (accessed December 28, 2020).
[20]https://www.syfy.com/syfywire/unconscious-patients-can-now-sort-of-speak-to-us (accessed December 28, 2020).
[21]https://encyclopedia.pub/2963 (accessed January 3, 2021).

phantom arm (e.g., bending the forearm against the elbow), perhaps even developing a self-schema and a feeling of ownership of this impossible arm (Moseley and Brugger, 2009)? The artist Stellarc played with such (im)possible cyborgian developments, by connecting a third arm to his body[22], for example, which also could be regulated from someone somewhere else via an internet connection. Stellarc related his performances explicitly to Haraway's cyborg vision of transgressing nature-techno boundaries alongside gender binaries (Hunt, 2015).

However, BCI researchers and developers do not name this obstinate material agency explicitly. This is my terminology only, drawing on the feminist materialist framework. For the developers, a certain disposal of control in online programming within the neuro-prosthesis seems to be indispensable. In BCI development, a freedom of learning should only be allowed if it is "effective but non-ambiguous" (Castermans et al., 2014, p. 35); it should improve the effectiveness of internal bio-technological interrelations, but maintain controllability. However, this raises the question of how much degree of freedom should be accorded to the BCI by this transfer. In the case of BCI development for rehabilitation of disabled functions due to age, disease, injury, or accidents, effectiveness *and* controllability of a BCI could be seen as legitimate and even essential. Unexpected bio-technological intra-actions in the closed loop could undermine rehabilitation and are to be avoided. Moreover, from a juristic point of view, the question of who is accountable is still not regulated: if, for example, a neuro-prothesis suddenly hits other people, is it the fault of the patient, the developer, the researcher or even the BCI itself, as (Clausen, 2006) asks?

For neuro-prosthetic developments, it is worth taking a look back at how it all started. The DARPA (the US Defense Advanced Research Projects Agency) financed most of the original research on the neuro-prosthetic development by Nikolelis and Lebedev. The Rehabilitation Institute of Chicago provided Jesse Sullivan, a double amputee from Tennessee, with two neuro-prostheses, regulated with nerve-muscle graft (Craelius, 2002). In 2005, he was presented as the "the World's First 'Bionic Man'" (referring to a 1970s TV series *The Six Million Dollar Man*) and as the first non-fictional cyborg (RIC, 2005). Jesse Sullivan was followed by Claudia Mitchel, a female and Black former U.S. Marine Corps officer—the bionic woman—who could regulate her neuro-controlled prosthesis (bionic arm) "simply by thinking" (RIC, 2006). RIC reported on the case of Jesse Sullivan in BBC News: "In fact, we are actively engaged in a proposal process to revolutionize prosthetics with the Defense Advanced Research Projects Agency of the US Department of Defense[23]." For example, the "Revolutionizing Prosthetics Program," launched in 2007 and extended in 2009, aimed at enabling injured soldiers to control an artificial arm via neuronal interfaces. Rehabilitation and operation readiness are not clearly separable. In this domain, medical applications and non-medical techniques of optimization in individual and weapon development cannot be distinguished sharply (cf. Schmitz, 2012). Hoag (2003) characterized the military sector as taking a predominant role in financing the development of BCI, neuro-prosthesis, and further neuro-technologies (Gibbs, 2008) for the faster, harder, fit-for-action, always ready-for-operation soldier. In the ARTE documentary Denjean (2017) the development of exo-skeletons and exo-prostheses is also mentioned as the latest innovations by the Nicolelis group.

In conclusion, despite their prima facie application scenario for the treatment of dis/abilities, neuro-prosthetic BCI also serves effectiveness in an analogous manner to the economic evaluation of affective BCI. There are other scenarios that call for an intersectional discourse around neuro-prostheses. For example, elite sports exhibit a severe binary division, mostly dominated by notions of masculinized bodies as muscular, powerful, and competitive; female bodies have to adapt to these signs of masculinity (Harasser, 2013), and this is only permitted up to a particular threshold. If a body is found to have exceeded the accepted threshold, as in the case of Caster Semenya's body, it will be excluded. Indeed, media representations underline the exclusion from their imaging choreographies of Non-white bodies considered to have an unfair advantage (Kleindienst-Cachay and Heckemeyer, 2008). Furthermore, a debate about fairness arises when, for example, runners like Oscar Pistorius with double leg-prostheses call for permission to join the competition between healthy athletes. The debate advanced arguments to the effect that athletes benefitting from such technologically enhancement would have an unfair advantage in the competition. However, other notions in this debate highlight elite sports as a "critical transformative room" (Crutzen, 2016), as when pharmacologically or technologically enhanced athletes are perceived as being superhuman cyborgs. Not only can these subjects no longer serve as displaying signs of dis/ability, but they are even celebrated as "ambassadors of transhumanism, placed at the cutting edge of human boundaries of capability" (Miah, 2003).

On the other hand, the use of prostheses has also erased a further evaluation of dis/ability—albeit with ambivalent meaning-makings. Victoria Modesta, calling herself a "bionic pop artist," deconstructs the notion of a leg prosthesis as a mark of dis/ability in her performance in "Prototype[24]" by acting with the prosthesis in various forms in a powerful and political scenario. Double leg amputee and top model Amie Mullins plays with up to 12 different pairs of prostheses on the cat walk as well as in artist performances; according to Garland-Thomson (2002), she creates an image of miraculous, sentimental, exotic, and realistic stereotypes in the popular media. A Syrian refugee, Ashraf Albesh, who was fitted with a prosthetic leg similar to those worn by Pistorius, "discovered his entanglement with the artificial leg as a means for dancing," amounting to the "diffractive transformation [...] into disturbance giving open space for new possibilities" (Schinzel, 2021). Knöppchen (2018) analyzed the campaign film *Die neue Nähe* [The New Proximity] made by the German dis/ability funding organization "Aktion Mensch." Focusing on the bodies, interactions, and communication in these film sequences, she investigated the extent to which the revision of notions of the *otherness* of

[22]http://stelarc.org/?catID=20265 (accessed December 28, 2020).

[23]http://news.bbc.co.uk/2/hi/health/4648139.stm (accessed December 28, 2020).

[24]https://www.youtube.com/watch?v=jA8inmHhx8c (accessed January 8, 2021).

people is even possible—and found some playful "encounters" between the people with disabilities and children in the film shots. However, she also found that the boundaries and normative conformity of the interacting "abled" and "dis/abled" partners had been reestablished.

For me, the question remains open as to whether neuro-prosthetic development may offer the possibility of changing the evaluation of dis/ability and uncovering obstinacies within prosthetic cyborgs over and beyond the astonishment elicited by exotic examples, or whether its embedding in the effectivity discourse will prevail.

Subject–Object Relations: The Machine Model

Remember, in the first BCI discourse, it was the human subject that was supposed to regulate the device with "thoughts." However, if developers progressively target unconscious or affective stimulation and mutual learning through brain plasticity and learnable algorithms or predict BCI calibration more accurately and effectively without involvement of a programmer within the closed loop, one also could argue that the BCI itself achieves a type of actor status through its obstinate agency. If the BCI acts, and if bio-technological intra-actions change directions, agents, and recipients, does the bio-technological agency then challenge notions of the subject–object relationship? Referring to the central paradigm of critical posthumanism is the notion of the intentional acting human subject decentered within the mutual conditioning between brain, body, computer, and neuro-prosthesis.

My analyses of recent publications in the field show that instead of a concept of obstinate agency or even subjectivity, BCI are reformulated as a comprehensive machine model. Moreover, the machine model defines the ground for targeting material traces anywhere in the bios, the techno or the silicon. Patients' "decisions" are termed "plastic conditioned pattern of brain activity" as, for example, when Castermans et al. (2014) argue for rehabilitation with a *robot-aided* BCI based on a concept of the "human locomotion machinery" or when a limb representation is termed a "completely novel body image … constructed solely by internally generated mechanisms" by Moseley and Brugger (2009, p. 18798). Miguel Nikolelis uses the machine metaphor to defend BTBI developments as follows: "Basically, we are creating what I call an organic computer[25]." Last but not least, in the ARTE documentary, Ken Hayworth, in two lengthy scenes at the beginning and the end of the video, claims that not only the brain, but also the "humans are programs." My hypothesis is that, once again, the machine model is being promoted to maintain control. Thoughts, decisions, experience, and subjectivity are bio-materially coded in a machine model of the whole BCI, including the human and the technology. Based on this notion only, and taking up the analysis of Stollfuß (2014), the vision of "Whole Brain Emulation" can comprise social role-fit emulation, mind emulation, and personal identity emulation. The main purpose is to trace, but what exactly will be traced in what direction?

[25]https://www.theguardian.com/science/2013/feb/28/brains-rats-connected-share-information (accessed April 25, 2017).

Opening the Closed Loop

The primarily conceptualized *closed loop* between the brain and the algorithms opens up toward input from outside in so-called *Brain-to-Brain Interfaces* (BTBI). In 2013, for the first time, the Lebedev/Nicolelis group reported a transfer of sensoric information from a so-called "*encoder*" rat to a "*decoder*" rat via a BCI in order to let the latter select a stimulus (Pais-Vieira et al., 2013). One year later, the development of BTBI between humans was already envisioned along with virtual information transfer between human brains over long distances via the internet (Grau et al., 2014; Rajesh et al., 2014). Besides public celebration of this "feasibility of a biological computer consisting of a network of animal, or human brains" (Gorman, 2013), there was also doubt about the validity of the data on direct brain transfer (Cossins, 2013). Interestingly, I could not find newer publications on concrete developments of BTBI in humans.

Trimper et al. (2014) name ethically problematic aspects of possible BTBI, e.g., neural privacy or informed consent, ownership of one's own thoughts (do they belong to the transmitting brain or to the receiving brain?), and also data security in information transmission via internet and the protection against hacking, in military applications, for example, or impacting the receiving brain with traumatic memories.

Interestingly, the first BTBI publications have also been referenced in economic affairs newspapers[26], hinting at the possible major targets of pathways within these developments. However, the visions of opening up the closed loop become evident in one of the most recent publications on *Human Brain/Cloud Interface* in *Frontiers in Neuroscience* (Martins et al., 2019). Here, the enhancement of human cognitive enhancement (referring to Kurzweil) as a prolongation of BCI and BTBI is anticipated. Based on the prospective application of nanorobots in the human brain, coined neuralnanorobotics, Martins et al. envision the development of a real-time interface between human brains and the internet via supercomputers and artificial intelligence algorithms, the B/CI, within the next 20–30 years. The concept is based on drawing a parallel between the "quantitative human brain," imagined as a huge depot for information storage, and the "cloud," i.e., the infinitive knowledge center in the internet. This project again builds on the neurobiologically determined neuroscientific model of the brain as connectome and an expected "non-destructive, real-time, secure, long-term, and virtually autonomous *in vivo* system" (Martins et al., 2019, p. 9, italics taken from the original): different types of neuralnanorobots implemented in the brain should enable it to be connected to the internet.

This amounts to the transformation of the vision of the "*in-silico* cerebral subject" proposed by Stollfuß (2014) into reality. The aligned prospects again reflect the colonial *white* Western masculinized notion of the to-be-enhanced. The targets of the B/CI are outlined explicitly, prompting several critical questions: "significant improvement in education" challenges what should be learned in future; "enhancement of

[26]In the heading "Telepathic rats team up across continents", the Financial Times reported about the BTBI experiments, https://www.ft.com/content/422e4e8a-8197-11e2-904c-00144feabdc0 (accessed February 28, 2013).

human intelligence" puts into question the form of intelligence envisaged; "artificial intelligence and existential risk prevention" refers to the advantage of AI over human intelligence by putting language capacities (sic!) at the center; and, finally, "transparent shadowing" reaches out to the transhumanist vision of virtual twins mirroring the host's life experiences and acting as attendees in various settings. What the authors really mean by highlighting the virtual autonomy of their cyborgian developing in line with the promise of control (security) remains an open question. Could that allow the appropriation and application of unforeseeable knowledge and actions?

VISIONS OF POSTHUMAN*ITIES*: TAKING UP THE INTERSECTIONAL STUFF

I have found some roots in BCI/BTBI developments that show pathways to serve transhumanist visions of technological enhancement leading to future upload of the mind to silicon. I have also discussed some possible unforeseen trajectories that could transgress intersectional categorization of a hierarchized masculinized, *white* on-the-top rationality over a feminized, underdeveloped unconscious affect. The shift to measurement of unconsciousness could open up cyborgian development to an obstinate bio-technological agency with diverse degrees of freedom; emotion-targeted BCI could up-value affect as a significant aspect of communication. All these are practices of un-taming the intersectional inscriptions within BCI. However, in upcoming practice, BCI/BTBI are mostly designed for enhancing effectiveness and competition of the individual in society. Effectiveness within the closed loop is achieved through control, while the machine model serves the idea that the matter of tracing thoughts could be equally bio or techno or biotechno.

The transhumanist agenda is strongly associated with "-isms" that always encompass political aims and norms. I have tried to gain political momentum with feminist STS and feminist–materialist approaches with regard to BCI phenomena that are addressed in transhumanist discourses and applying concepts of neuro-governmentality. Referring back to my setup of the tension between a cyborgian potential to transgress gendered and intersected binaries, respectively, to deconstruct the discriminatory assignments thereof, and the danger of powerful practice of domination through informatics, I revise the development of the "*in-silico* cerebral subject" (Stollfuß, 2014) within socio-cultural power relations. In order to gain and fulfill biological citizenship (Rose and Novas, 2005), the Western dispositives of personalization, self-responsibility, and particular enhancement goals still legitimize social positioning and societal success (Pitts-Taylor, 2010; Schmitz, 2012). The combination of invocations demanding a self-responsible application of neuro-technological enhancement underpinned by the gendered and racialized ideologies and normative demands of current neuro-governmentality (Maasen and Sutter, 2007) point to the particular adoption of masculinized *white* norms and values in these developments.

What is happening today outside the health sector is the development of techno-human enhancements to achieve a spectrum of particular objectives, with controlling bodies and their capabilities within the work environment (Farah et al., 2004; Schmitz, 2012). Capitalist-compatible techno-enhanced physicality turns out more and more to be a critical success factor in the construction of identities and the profit-oriented marketing of one's own labor with flexibility, competitiveness, rational productivity, concentration, effectiveness, multitasking, and efficiency available on demand. Surgical techniques, Ritalin or Prozac intake, Brain Caps, or internet connections all increasingly intervene in the body, so that the postmodern *white* Western subject becomes caught in the wheels of improvement, expansion, and optimization under the slogan of "feasibility rather than fate." Enhancement techniques for any kind of skills and moods based on notions of brain plasticity are promised for everyone (see, Greely et al., 2008 in *Nature*), seemingly regardless of gender. However, analyses from a feminist perspective have shown that gendered attributions are (again) produced in scientific and popular discourses concerning the applications and practices of neuro-enhancement (e.g., Blum and Stracuzzi, 2004; Höppner and Schmitz, 2014).

In addition, the repeated references to thoughts and minds as the driving forces of neuro-enhancement produce an image of the conscious and self-confident subject that uses the technologies for her/his own aims and needs. The apparently autonomous setting of human decision-making and controlled communication masks the embedding of these self-technologies in current neuro-governmental bio-politics and the interplay of research policies, markets, and state politics (Pickersgill, 2013). The other side of the coin is control: technologies for face recognition, border control against *others*, namely, Non-white immigrants that are not supposed to enter the North-Western sphere. Learnable algorithms that surf the internet promote prejudice Black people and women simply by taking up precisely what humans have posted (Noble, 2018). Racial profiling and predictive policing tools that link "places, events, and historical crime rates to predict where and when crimes are more likely to happen" generate sexist, racist, and classist discrimination (Heaven, 2020) and so forth. A lengthening of this list would go far beyond the scope of this paper. I have considered the military sector in relation to the aspect of control, because it plays a predominant role in financing the development of BCI, neuro-prosthesis, and further neuro-technologies (Hoag, 2003).

Despite this seemingly overwhelming continued predominance of colonial masculine power, it is important to formulate strategies for responsible and accountable research, development, dialogue, and discourse for the realization of TechnoBrainBodies-in-Cultures *in other ways*. Cecilia Åsberg's perspective of posthuman*ities, a* "philosophy and sciences informed by advanced cultural critique and some seriously humorous feminist creativity [. . .] and inventive feminist materialist philosophies" aims at joining "postdisciplinary arts and sciences informed by cultural critique and feminist creativity" to research and at discussing "the more-than-human condition[27]." With this perspective of posthuman*ities,* and trying to imagine speculative turns within the developments of BCI to

[27]https://posthumanities.net/om/ (accessed January 6, 2021).

mind upload, I have tried to challenge the term transhumanism and assess the impact of heteronormative and intersectional inscriptions in TechnoBrainBodies-in-Cultures, while at the same time trying to find even small windows of obstinacy, unforeseeable possibilities in development and reinterpretations of the meaning of what should be enhanced.

In my view, potential idiosyncratic practices within TechnoBrainBodies-in-Cultures, unforeseeable agencies, and an openness for the diversity of their realizations are more to be welcomed than feared. The point is that cyborgian developments, so far, have not realized uncontrollable autonomous agencies that could control or dominate humans or human societies. These are only fictional horror scenarios. Instead, it is the sphere of human developers and practices with their targets, concepts, and realizations in creating TechnoBrainBodies-in-Cultures that needs to be subjected to critical discourse in order to further an open and non-discriminatory posthuman*ities* debate. Following this approach obstinacies could also be envisioned for obstinacies could also be envisioned for cyborg futures, embracing components such as affect, sociality, contumacies, uncontrollable bodily agencies, as well as idiosyncratic agencies and contumacies. The term posthuman*ities* thus becomes clearly distinguished from transhumanism. One way would be to conduct an in-depth search for further examples of TechnoBrainBodies-in-Cultures realizations and trajectories that exhibit cultural and ethnic diversity, age, illness or dis/abilities, and multiple sexes/sexualities.

Another could be to encourage critical reflection of the field by the public and the academic world, namely, by developing neuro-literacy formats. Ashley Baccus-Clark, a molecular and cellular biologist, multidisciplinary artist, performer, writer, and "brand strategist," works collectively in Hyphen-Labs with other women of color, "at the intersection of technology, art, science, and the future" (Hyphen-Labs, 2020), and develops academic-arts performances, e.g., NeuroSpeculative AfroFeminism, a virtual reality project that unfolds visions of neuroscience and neuro-technology in other ways (Baccus-Clark, 2020). As a result of the most recent conference of the NeuroGenderings network in Leiden 2020, a group of neurofeminist-arts scholars and myself have now initiated a working group for developing "neuro-literacy" at the intersection of STS and arts/performances.

This paper is a start and a call for NeuroGenderings scholars to join in a transdisciplinary working group for developing further analyses within a posthuman*ities* perspective. My vision is to regard TechnoBrainBodies-in-Cultures as cyborgian companion species instead of enhanced competitors (Haraway, 2003), with all their inexplicabilities, unpredictabilities and idiosyncrasies, vulnerabilities, and incompleteness, that could support us in challenging neurobiological determinism and anthropocentrism.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

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

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Gender Beneath the Skull: Agency, Trauma and Persisting Stereotypes in Neuroepigenetics

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Epigenetics stands in a complex relationship to issues of sex and gender. As a scientific field, it has been heavily criticized for disproportionately targeting the maternal body and reproducing deterministic views of biological sex (Kenney and Müller, 2017; Lappé, 2018; Richardson et al., 2014). And yet, it also represents the culmination of a long tradition of engaging with developmental biology as a feminist cause, because of the dispersal of the supposed 'master code' of DNA among wider cellular, organismic and ecological contexts (Keller, 1988). In this paper, we explore a number of tensions at the intersection of sex, gender and trauma that are playing out in the emerging area of neuroepigenetics - a relatively new subfield of epigenetics specifically interested in environment-brain relations through epigenetic modifications in neurons. Using qualitative interviews with leading scientists, we explore how trauma is conceptualized in neuroepigenetics, paying attention to its gendered dimensions. We address a number of concerns raised by feminist STS researchers in regard to epigenetics, and illustrate why we believe close engagement with neuroepigenetic claims, and neuroepigenetic researchers themselves, is a crucial step for social scientists interested in questions of embodiment and trauma. We argue this for three reasons: (1) Neuroepigenetic studies are recognizing the agential capacities of biological materials such as genes, neurotransmitters and methyl groups, and how they influence memory formation; (2) Neuroepigenetic conceptions of trauma are yet to be robustly coupled with social and anthropological theories of violence (Eliot, 2021; Nelson, 2021; Walby, 2013); (3) In spite of the gendered assumptions we find in neuroepigenetics, there are fruitful spaces – through collaboration – to be conceptualizing gender beyond culture-biology and nature-nurture binaries (Lock and Nguyen, 2010). To borrow Gravlee's (2009: 51) phrase, we find reason for social scientists to consider how gender is not only constructed, but how it may "become biology" via epigenetic and other biological pathways. Ultimately, we argue that a robust epigenetic methodology is one which values the integrity of expertise outside its own field, and can have an open, not empty mind to cross-disciplinary dialogue.

Keywords: neuroepigenetics, gender, trauma, plasticity, interdisciplinarity, family violence, qualitative research, neuroscience

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INTRODUCTION: BIOLOGY BEYOND THE GENOME

In the wake of the Human Genome Project, molecular biology has undergone some fascinating changes. In particular, common understandings pertaining to the simple genetic determination of phenotypes is being challenged by advances in postgenomic sciences. What has been called "missing heritability" – the elusive correlation between genetic variants and common traits or complex diseases – not only exemplifies the lack of explanatory power of gene-centric explanations (Maher, 2008; Pennisi, 2012; Lock, 2015) but has increasingly pushed scientists to look at the wider architectural complexity surrounding gene expression, from cell to society, to account for environmentally sensitive variations in bodies, health and disease (Keller, 2011, 2014; Landecker, 2011; Niewohner, 2011). Rather than genetic mutations being unresponsive to the environment during the lifespan, postgenomic thinking explores how the environment comes into the body and modulates the genome in relatively short time frames (Keller, 2010, 2015; Charney, 2012; Landecker and Panofsky, 2013; Moore, 2015; Warin and Martin, 2018).

This postgenomic shift (Griffiths and Stotz, 2013; Richardson and Stevens, 2015; Meloni, 2016, 2019; Baedke, 2018) parallels the growing appreciation of experience-dependent plasticity in the human brain throughout life that "has drawn attention to the crucial role that the outside world—the lives we live, the jobs we do, the sports we play" continuously have on brain functioning and the nervous system (May, 2011; Chang, 2014). As neuroscientist Gina Rippon (2019: 235) notes:

> It's no longer a question of our brains being a product of either nature or nurture but realizing how entangled the "nature" of our brains is with the brain-changing "nurture" provided by our life experiences.

A similar move toward an entanglement of nature, nurture and plasticity of genomic functioning is represented by the expanding field of epigenetics: the study of mitotically (cell division) or meiotically (sex cell division) heritable changes in gene function that cannot be explained by changes in genetic sequence. In epigenetic language, environmental "signals" and "exposures" are said to alter the configuration of epigenetic markers, such as methylation (i.e., the addition or subtraction of methyl groups), non-coding RNAs and histone acetylation. Through these contemporary reconfigurations, genes are understood less as growing and operating on their own. Instead, they are considered part of a complex biochemical assemblage that - by virtue of its material constitution - allows for change and transformation in response to the surroundings of a cell, organ and organism in the broadest (and perhaps vaguest) sense. Some epigenetic studies (primarily using animal models) are also suggesting that epigenetic modifications can be carried through the germ line, and thus can be inherited across generations (Jablonka, 2013; Sharma, 2013).

Based on some of the cross-disciplinary commentary of epigenetics, especially feminist Science and Technology Studies (STS), it is clear that the field of epigenetics stands in a complex relationship to issues of sex and gender. As a scientific field, it has been heavily criticized for disproportionately targeting the maternal body and reproducing deterministic views of biological sex (Richardson et al., 2014; Kenney and Müller, 2017; Lappé, 2018). And yet, it also represents a long tradition of engaging with developmental biology as a feminist cause, because of the dispersal of the supposed "master code" of DNA among wider cellular, organismic and ecological contexts (Haraway, 1976; Keller, 1997, 2002). Moreover, it is from epigenetics that some less known but fascinating studies on paternal exposures (nutrition, stress, and smoking) have recently arisen, complicating the usual focus on maternal blame when it comes to "pathologizing" effects on their offspring (Rando, 2012, 2016; Rodgers et al., 2013; Soubry et al., 2013; Gapp et al., 2014, 2016; Soubry, 2015; Andaloussi et al., 2019; Le Blévec et al., 2020). This reorientation is part of a wider evolutionary rethinking about the role of paternal care (or biparental care) in mammals, which has emerged in these last few years (Pilakouta et al., 2018). Although there is clearly a shift in interest toward paternal epigenetic transmission - a shift which has been welcomed by many in the field – the conceptual discussion about gender - as lived, multiple and complex - is lacking. This is especially clear in studies exploring the epigenetic impact, imprint and transmission of trauma and stress.

In this paper, we explore a number of tensions at the intersection of sex, gender and trauma that are playing out in the emerging area of neuroepigenetics - a relatively new subfield of epigenetics specifically interested in environment-brain relations through epigenetic modifications in neurons, which may subsequently affect their function, lifespan and capacity to retain memories. Although still in its infancy, neuroepigenetics is particularly salient as it arises at the crossroads of two trends that have attracted much attention over the last few decades: firstly, the biological embedding of social experience, meaning the process whereby life experiences produce "lasting changes in the function of a biological system with consequences for development, behavior, and health" (Aristizabal et al., 2020). Secondly, what sociologist Nikolas Rose and colleagues have recently termed "neuroecosociality," an integration of biological and social understandings that builds upon emerging findings from neuroscience to find mechanistic pathways that explain trajectories of well-being and disease (Rose et al., 2021).

In a series of qualitative interviews[1] with leading scientists carrying out research on epigenetic effects in the brain, we explore how trauma is conceptualized in neuroepigenetics, paying particular attention to its gendered dimensions. In so doing we address a number of concerns raised by feminist STS researchers in regard to epigenetics, sex and gender and illustrate why we believe close engagement with neuroepigenetic claims, and neuroepigenetic researchers themselves, is a crucial step for social scientists interested in questions of embodiment and trauma. We argue this for three reasons. Firstly, neuroepigenetic studies are recognizing the agential and reactive capacities of biological

[1]Interviews were conducted internationally by one of us (EL-B) over the course of 2020 as part of a Ph.D. project at Deakin University, *Biological biographies and molecular memories: A study of epigenetics and how trauma gets under the skull.*

materials such as genes, methyl groups and particular sections of the brain, and how they affect the body's stress response system and memory (Reul, 2014). Secondly, neuroepigenetic conceptions of trauma are yet to be robustly coupled with social and anthropological theories of violence (Walby, 2013; Eliot, 2021; Nelson, 2021). Many scientists interviewed for this study are engaging in questions about embodied and inherited trauma, yet in interviews as well as in peer-reviewed journal articles, the issue of types of violence has been scarcely mentioned. This may be in part attributed to specialization between disciplines institutionally, as well as lack of cross-disciplinary dialogue. For example, neuroscientist Thomas Lai[2] (Melbourne) in our interview expressed frustration with a supposedly lack of productive cross-disciplinary conversation:

> TL: It struck me that [. . .] people aren't really talking to other people, and there's a danger in that, because you are so single minded and focused on your own pursuits that it's very dangerous, if you're going to ignore the other fields as well. You shouldn't be excluding them; you should be incorporating them into your work.

In response to researchers like Thomas, we use this paper to raise a very simple but vital methodological step available to all parties: cross-disciplinary dialogue.

Thirdly, in spite of the problematic assumptions we find in neuroepigenetics regarding gender, there are also fruitful spaces – through collaboration – to be conceptualizing gender beyond culture-biology and nature-nurture binaries (Lock and Nguyen, 2010; Lock and Pálsson, 2016). It is important to note that the third point is more peripheral as far as this paper's scope goes, but we raise it here nonetheless because our exploration of gender and trauma in a neuroepigenetic context has inevitably led to questions about the relations between exposures and "material bodily difference" (Guthman, 2014). Bodily difference, as a construct informed by postgenomic ideas, gestures less to a body pulled between the boundaries of nature and nurture, and more toward reactive, relational conceptions of human life and embodiment (Lock and Pálsson, 2016). To borrow (Gravlee's, 2009: 51) phrase, we find reason for social scientists to consider how gender is not only constructed, but how it may "become biology" via epigenetic and other biological pathways. Thus, we argue that there is a need for feminist STS to be considering "biosocial differentiation" (i.e., the ways in which bodies and bodily substrates are modified relative to history, politics, economics and socialities in multiple time scales), and how modes of gendered violence play a role in this differentiation (Lock and Nguyen, 2010). As it has been shown in the case of racism and food justice, epigenetics lends itself to biosocial conceptualizations of difference as simultaneously cause and consequence of social injustices, without reducing them to matters of genetics or culture alone (Guthman, 2014).

Beyond this paper, and with insights from the postgenomic sciences, we see empirical opportunities for social scientists to consider gender – as well as gender inequality and violence – as a biologically absorbable, differentiating and transmittable agent (Roy, 2016; Cortés et al., 2019). The recent history of feminist theory can be characterized by overt concern of biological reductionism, determinism or evolutionary explanations (often driven by genetics), of sexual differences, as a way to naturalize (and hence justify) existing social and cultural inequalities and behavioral or psychological dimorphism between women and men (Fausto-Sterling, 1993, 2012; Fine, 2010; Richardson, 2013; Joel and Vikhanski, 2019; Mikkola, 2019). However, akin to our interlocutors from feminist neuroscience (Roy, 2016; Fine et al., 2017; Rippon, 2020), critical neuroscience (Choudhury and Slaby, 2011) and feminist STS (Haraway, 1988; Wilson, 2004), we believe that multi-disciplinary analyses of biosocial difference to be a progressive epistemological step, and will no doubt raise questions about the ways in which social justice movements conceptualize the body.

In these encounters, we anticipate that a "critical friendship" between neuroepigenetics, feminist STS and medical anthropology – however precarious a process this may be – will not run counter to emancipatory ends, but support them (Rose and Abi-Rached, 2013; Fitzgerald and Callard, 2015; Roy, 2016). Although we do not attribute any inherent emancipatory meaning by itself to epigenetics (Mansfield and Guthman, 2015), the peculiar hybrid nature of knowledge production in epigenetics, which constantly criss-cross the boundaries between the social and the biological, may prove a very fertile ground to put to test the feminist incorporation of molecular biology (or molecular feminisms) in order to generate differences "not through lack but rather through positive and productive senses" (Roy, 2018). There is potential for neuroepigenetics not simply to challenge the notion that biology and biological processes are naturally "essentializing or deterministic" (Roy, 2018: 5), but also to question how particular neurobiological "actants" – hormones, genes, synapses and neurotransmitters – play their part in the making of subjectivities (or phenotypes) that is uncleavable from social, political and geographical exposures (Richardson, 2017; Cortés et al., 2019).

We say actants rather than "substrates," "bases," or "underpinnings," because we believe that there is scope within epigenetics to challenge naively foundationalist views of biology according to which, in Susan Oyama's developmentalist critique, one can move from the social to the biological as going "'down' the layers (. . .) from effect to cause, from the provisional to the immutable, from the trivial to the profound (. . ..)" (Oyama, 2000: 164–5; Meloni, 2014). Also, in the words of philosopher Samantha Frost (2016, 2020), there is potential in epigenetics to imbue matter with meaning and agency, breaking the supposed association of fleshiness "with the unintelligent and the imperceptive." The *attentive body* that she sees emerging from a theoretically aware connection of epigenetic science and living experience, can be refashioned here as an "attentive brain," where epigenetic marks of trauma are not just an inert sign established by blind mechanistic forces, but part of the wider "embodied responsiveness" of an organism-in-context that "is at once inhabited by the traces of its past and seeded with traces of its future" (Meloni and Testa, 2014: 15; Frost, 2020; see also Meloni and Reynolds, 2020).

[2]In adherence with this project's ethical parameters, all identifying markers in transcripts have been removed and replaced with pseudonyms.

Ultimately, we argue that a robust and feminist postgenomic methodology is one which values the integrity of expertise outside its own field, and can have an open, not empty mind to cross-disciplinary dialogue. We foreground this argument in this special issue primarily because it has come from neuroepigenetic scientists themselves, who are calling for cultural reorientation which can respectfully account for other modes of knowledge, other reference points, and genuine collaboration across disciplinary fields.

To make this point a more salient one, and indeed, to gesture to the notion that gender may indeed have neurobiological agency (Higgins, 2018), in section four we make reference to the concerning rates of family violence during the COVID-19 crisis in Australia (where we are both based). We hope this will also illustrate why epigenetic researchers need to be cautious of unknowingly re-hashing gendered stereotypes, as they have epistemological consequences for the ways in which trauma research is carried out. Our attention to a particularly invisible type of violence - which remains socially, culturally and politically widespread, yet necessarily provincial – acts as both a caution about making gender-based assumptions, and a rationale as to why neuroepigenetic conceptualizations of trauma at the very least need to be informed by empirical and theoretical studies of violence. In the vein of our epistemological commitment, and in a feminist STS tradition, we urge biological and social scientists to consider what allowances and restrictions their positioned perspective offers (Haraway, 1988). A point on our methodology: we assume and trust in first impressions (Schwartz, 2002); that what was said during interviews is to be taken as genuine, at "face value" and in good will.

NEUROEPIGENETICS: NEUROBIOLOGICAL CHANGE AND MEMORY

Formally introduced by neurobiologist Jeremy Day (University of Alabama at Birmingham) and neuroscientist David Sweatt (Vanderbilt University), neuroepigenetics is foregrounded not only as reformulating "the fundamental existential question of nature versus nurture" but also as having the potential to sharpen current knowledge about the cognitive and psychic impacts of life experiences (Day and Sweatt, 2011; Kim et al., 2018; Coda and Gräff, 2020). Evoking the controversial theory of the "engram" - a (hypothetical) biophysical change in the brain that accounts for the material existence of memory (Josselyn et al., 2015: 201) - Day and Sweatt suggest that epigenetic mechanisms, such as DNA methylation, may be a window into the brain's memory. The epigenome is said to be a crucial "missing link" between life experiences and gene expression, which in turn will influence the ways in which neuronal circuitry and brain structures develop. In regard to Post-Traumatic Stress Disorder, Day (University of Alabama at Birmingham, 2015)[3] claims an existing correlation between neuro-epigenetic markers, memory and traumatic experience; by removing or altering epigenetic markers, the "negative" impacts of trauma may be manipulated and even possibly erased (Schmidt et al., 2013).

While neuroepigenetics has emerged only in recent years, the relationship between epigenetic changes and memory is far from being occasional or incidental. Firstly, as Day and Sweatt's reference to the engram model evidences, epigenetic views of embedded experiences in the brain today resonate with influential late nineteenth and early twentieth century models of organic memory, although not necessarily adhering to the same neo-Lamarckian framework (Semon, 1921; Otis, 1994; Schacter, 2001; Szyf, 2014; Logan, 2015). Contemporary ideas of plasticity, brain receptiveness, experiential inscription and traces were a major part of these post-Darwinian debates that were later challenged by the rise of genetics (Chiapperino and Panese, 2019).

Secondly, epigenetics has opened new avenues in the last decade to wider research programs on synaptic plasticity and the neurobiology of memory (Landry et al., 2013) highlighting how epigenetic functioning and chromatin reshaping may underpin short and long-term memory processes, associative learning, and social cognition (Fagiolini et al., 2009; Ferrari et al., 2013; Post, 2016). By this, memory and indeed experience reflects biological differentiation. Epigenetic markers - or the epigenome - are said to act as the "the molecular memory" of by-gone stimuli, which allows a cell to "remember" past events that an organism has experienced (Bonasio et al., 2010: 612; see for a precursor Holliday, 1999). In the context of our article, we highlight in particular recent research on the importance of sex-specific epigenetic patterns in early life as a form of cellular memory that contributes to the establishment in adulthood of brain sex differences in animal models (McCarthy et al., 2017).

Thirdly, key epigenetic studies in animal models originate from or directly cut across neuroscience research which gravitate around topics of trauma, stress and their potential transmission across generations (which still remains a controversial argument) (Weaver et al., 2002, 2004; McGowan et al., 2011; Dias and Ressler, 2014). Since the late 1990s neuroscientists and molecular biologists have been fascinated with the brain's capacity to be physically shaped by its social and material environment, particularly the maternal environment (Kim, 2021), especially during the earliest years of life (Francis et al., 1999; Coda and Gräff, 2020). During this time, the argument goes, neural cells are rapidly dividing as the body grows and thus the brain is perceivably more vulnerable, or in other words, more plastic (Fagiolini et al., 2009; Szyf, 2009). Not only are epigenetics considered mechanistically crucial for the shaping of neural pathways, but also for the ways in which somatic cells differentiate and perpetuate cellular phenotypes over time (Feinberg, 2007). Epigenetic changes in gene expression thus have emerged as an important mechanism that mediates the brain's structural plasticity in periods of particular sensitivity (Cortés-Mendoza et al., 2013; Babenko et al., 2015).

Emerging from earlier research programs on the neuroepigenetics of memory (Zovkic et al., 2013a,b), the rate of neuroepigenetic studies on trauma, adversity and mental illness are growing fast, in some cases including claims about transgenerational inheritance or collective/historical

[3]https://www.sciencedaily.com/releases/2015/01/150121114604.htm

trauma (Curry, 2019; see overview in Thayer et al., 2017; Yehuda and Lehrner, 2018; Dubois and Guaspare, 2020; Warin et al., 2020). For instance, a recently published edited book (Rutten, 2018) includes a selection of work addressing topics such as the transgenerational epigenetics of stress (Jawaid et al., 2018), neuroepigenetics of PTSD (Kim et al., 2018), as well as the central neuroepigenetic regulation of the hypothalamic-pituitary-adrenal-axis (Dick and Provencal, 2018; Montenegro et al., 2019). In addition, a *Frontiers* special issue on "Epigenetic Pathways to PTSD" featured thirteen articles from DNA methylation as biomarker in the detection of PTSD, to sex-specificity of stress responses (Roth, 2014).

Importantly, the studies included in the special issue suggest that genes have innate sensitivity and responsiveness which may have significant consequences for the ways in the nervous system – and in particular, stress response system – develops. As Roth (ibid., 3) explains:

> Epigenetic mechanisms are a class of molecular mechanisms by which environmental influences, including stress, can interact with the genome to have long-term consequences for brain plasticity and behavior. As PTSD, by definition, requires exposure to a traumatic event, and because genes are exquisitely sensitive to stress and trauma, epigenetic alterations have received attention as possible contributors to the development and persistence of PTSD symptoms.

As two key scientists in the field, Michael Meaney (McGill, Montreal) and Rachel Yehuda (Mount Sinai Hospital, New York) observe in a co-authored chapter, this is not quite the same that noting the well-recognized "transient alterations in neural, endocrine or immunological signals that follow exposure to trauma"; unlike those "transient" variations, there is a stronger emphasis that "certain epigenetic markers can be chemically *stable* over extended periods of time and thus serve as the basis for an understanding of the *persistence* of PTSD symptoms" (2018: 293-294, our italics). Nonetheless, persistence does not mean fatalism, as in classical 'faulty gene' narratives: DNA methylation, while chemically stable, is *nevertheless reversible*, offering potential insights into future treatments for PTSD" (ibid.: our italics). We will explore in our interviews these tensions between passivity and agency, determination and reversibility, trauma and hope, that shape one of the key narratives of scientists in the field.

To sum up, if epigenetic research discursively blurs the line between body and milieu, allowing environments to "get under the skin" (McEwen, 2012), then neuroepigenetics looks at experiential *traces going under the skull*, and become *literally engraved* – for better or for worse – in the brain (Plazas-Mayorca and Vrana, 2011). Although the discussion we provide above will no doubt evoke suspicions for social scientists vis-a-vis the ways which neurobiology is materially and discursively responsive, beyond the potential hype and hope we find that neuroepigenetic ideations present an opportunity to frame the nervous system as a psychosomatic political site, where questions of gender, trauma and biosocial differentiation emerge. Based on neuroepigenetic ideas of neurological impressionability, as well as the nervous system's vulnerability to "exposures" as a result, we urge social scientists to re-consider the agential capacities of flesh and what it might mean for analyses of violence. There are of course potential pitfalls in this kind of figuring, yet based on the advocacy expressed in range of literatures on bio-psycho-socialities (Blackman, 2016), feminist neuroscience (Roy, 2016), disability studies (Shakespeare, 2006; Goodley, 2011) as well as metabolism studies (Solomon, 2016) and food sovereignty (Guthman, 2014), neuroepigenetics lends itself well to an articulation of embodiment that may simultaneously decenter and situate the brain without reducing its material complexity (Roy, 2016).

If neurobiology *gets* and stays different through exposure, we ask here how much of it gets gendered too, by virtue of its material and relational constitution. And if it does, how can we incorporate a wider and sharper scope of social, political and biological agents into our analyses where matter and mattering are taken seriously "against the limits" of representational or constructionist paradigms (Grosz, 1994; Pitts-Taylor, 2016). We find this a pressing and timely task, not only as it points to generative possibilities for collaborative research, but also because of the ripple effects neuroepigenetic research may have in other nascent fields. From this brief review of current neuroepigenetic postulations, we find that the brain's responsiveness to trauma is clearly at the frontier of this growing field, yet we also find a number of issues regarding trauma's conceptual parameters, as well as the way in which types of violence are being neglected. In both the neuroepigenetic literature and our own interviews, the nuances of particular types of violence such as interpersonal, structural, collective and gender-based (Rutherford et al., 2007) are seldom addressed as agential. Moreover, definitions of stress and trauma are situated primarily in physiological, reproductive and neurological processes of the *sufferer*, which raises the question of how social and political agents can be given credence in this framing. This is a significant issue for the field, and we suggest that further contributions from feminist STS and medical anthropology are needed to address this. In the next section, we discuss some conceptions of trauma as described by leading neuroepigenetic researchers.

TRAUMA'S NEUROEPIGENETIC AGENCY/LEGACY

Trauma, often taken for granted in both scientific and popular literature, is not a clearly defined object existing "there" in the world, nor is it a timeless category. Applying Allan Young's classic analysis of PTSD, we can also say that trauma as a distinctive concept and independent disease is the relatively recent historical result of a number of narratives, technologies and epistemic practices "with which it is diagnosed, studied, treated, and represented by various interests, institutions, and moral arguments that mobilized these efforts and resources" (Young, 1995: 5). We see the growing centrality of ideas of trauma in epigenetics and neuropigenetics literature emerging at the

intersection (or possibly culmination) of three important cultural trends that have taken place over the last two decades.

Firstly, there has been a massive expansion and cultural legitimation of ideas of traumatic victimhood in political, legal, and humanitarian contexts (Fassin and Rechtman, 2009) and more recently, in healthcare (Müller and Kenney, 2020). Secondly, there has been a shift from a psychodynamic view of trauma (i.e., trauma as the result of a conflict within the subject triggered by external conditions) to a *literalist* view of trauma as a "reality imprint in the brain (. . .) undistorted and uncontaminated by subjective meaning" (Leys, 2000: 7, see also Chapter 8). That is, to simplify, while a psychodynamic model emphasized unconscious conflicts internal to the subject as a source of trauma, the literal model highlights the pre-representational, veridical nature of trauma as literally engraved or etched in the brain beyond and before cognition (Leys, 2000, pp. 250 and ff.). Thirdly, emerging forms of "biolegitimacy" (Fassin, 2009) in which biologically validated knowledge about suffering is turned into a platform for political recognition. Described as "an historical testimony of colonial violence" (Warin et al., 2020: 4), epigenetics and other versions of bio-legitimized trauma are part of a growing trend where biological knowledge is recognized as possessing more authority than other forms of witnessing trauma (historical, narrative, phenomenological etc.).

In interviews with neuroepigenetic researchers, we explored how trauma is defined and recognized in their field. Although interviewees generally considered trauma elusive and subjective (i.e., it doesn't appear to have a universal, clearly defined or standardized definition), they describe trauma as, in part, an objective neurological phenomenon innate to sufferers, and that can be better understood and treated once underlying biochemical mechanisms involved are identified. Trauma involves a plethora of chemical, neurological and cellular agents, thus rendering traumatic experiences neurologically affective in temporal, material and *sticky* ways. In other words, trauma – unlike stress, or far more than stress – stays under the skull and is particularly difficult, yet possible, to "fix." For instance, when talking to Professor Alexander Berman, a veteran and leader in the field of epigenetics, he explained:

> AB: You know what is stressful is subjective, but the only objective criteria we have is release of the stress hormone. So, if you define anything that releases stress hormone consistently it is stressful, and in fact it might vary between people right? But I think in the end it has to be mediated through some biochemical pathway, and the medical consequences will be how much this fires, so I will say that as a biochemist you know I will define it as a release of stress hormones and consistency of the release of stress hormones, but they could be released by anything.

Similarly, neuroepigenetic researcher Professor Lukas Birrer described trauma as "an extreme form of stress"; a little bit of stress is for the most part beneficial, he explained, but when "it becomes too much or prolonged, then this can lead to unhealthy consequences" for the body. Here, the discursive "consequences" of trauma (which we can assume to include psychiatric outcomes such as Post-Traumatic-Stress-Disorder etc.) are in part a result of temporally excessive amounts of stress hormone released in response to a significant (and vaguely defined) stressor.

The notion of consequence – be that medical, unhealthy or otherwise – begs a number of questions for epigenetic scientists regarding matters of ontology and scale: *what* characterizes respective neurological and epigenetic markings pertain to a past stressor, and what might be the negative effects of those markings for minds, bodies and collectives? Although the potential answers to these questions remain conceptually ambiguous and empirically contentious within the field, what we find to be consensus is the necessity to and relative difficulty of removing these markings.

In an interview with Adele Charlier, a leading neuroepigenetic researcher based in Western Europe, we asked what differentiates stress from trauma, to which she explained:

> AC: Stress is usually defined biologically by the stress pathway. Or the release of stress hormones, due to something which happened to you which can be acute or chronic. Trauma is something very different, not very different, trauma includes some of the stress effect, but it has more to it. . .There is not enough knowledge to know exactly what epigenetic alterations can be repaired, because I don't think there is a single answer to this. It depends on when and to what extent the epigenome has been interfered with, modified. You know, if it happens early in life, due to a chronic exposure, I think it's quite intuitive to me, that it's going to be embedded into the body and that may be difficult to. fix this, or normalize or correct it, because the system will have never been normal, in a way. It's the same with psychiatric disorders. Children who are abused. . .who are exposed to trauma very early on, it just shapes their body, and then if something is badly constructed from the beginning, you cannot fix it later in life. It's not completely impossible, unlike the genome, which there is limitation you cannot fix it, the epigenome is dynamic.

In this framing, trauma – as a biologically detrimental and impressionable form of stress which acts as a foundation for life trajectories - is literally formative through relatively chronic stimulation of chemical and molecular pathways, especially during early life, and in turn, creates particular kinds of long lasting molecular and cellular change. Trauma is materially unique here in terms of its biological presentation; unlike stress, which is relatively normative, likely to go away in shorter periods of time and even beneficial, trauma represents a significant physiological deviation that, when stable in the sufferer, crystalizes in the form of long-lasting (but not necessarily permanent) biological mechanisms such as epigenetic alterations and memory formation. Similarly, during Alexander's interview, he was asked the question:

> Q: Do you think epigenetics then offers I mean it can act as proof or as evidence the trauma has been there somewhere in the past?

> AB: Yes, yes, if it's done well and yes of course it will show the most proximal mark in DNA, which will show its relationship to stress. And it also provides a psychical mechanism of how stress can be embedded and how stress can be even passed to other generations. . . So if you were abused as a child it has two components, the abuse itself that happened, that's history, don't erase it. But now erase what that abuse *did on your DNA*, because what it did to your DNA is causing you a problem today, so essentially you're suffering from an abuse that doesn't exist because it exists in the past.

In this case, traumatic impression – as both epigenetically mediated and as a sign of past events – is characterized not just as a wound inflicted on body, mind or soul, as in the ancient Geek etymology of traûma, "wound, damage",[4] but a wound inflicted on DNA itself. And the consequences for neurology and memory are paramount. As we described in the last section, neuroepigenetic researchers postulate that short and long-term memories are in part mediated by epigenetic pathways, and are characterized by the location they are stored in the brain. Not only are differences in location and epigenetic mediation central to the ways in which trauma becomes embedded in the brain, but also to the ways in which it can be "erased" or "treated." As Lukas explained:

> LB: In another study out of my own lab, we showed that long lasting traumatic memories are stored much more differently than recent ones. I mean that short term memories, which we call remote and recent memories respectively, these remote memories, what makes them become stored differently is that their epigenetic make up in their specific brain areas is different, so they are *less plastic*, so they are more condensed and that [. . .] makes them harder to be erased or to be treated with therapy.

Although interviewees pointed out that the evidence supporting neuroepigenetic claims remains thin, and in turn "there is not enough knowledge to know exactly what epigenetic alterations can be repaired," these statements suggest a kind of speculative future for interventions and treatments whereby micro-matter like epigenetic markers may be targeted; having an epistemological handle on the biophysical and biophysically mediated trace of trauma in the brain raises the possibility of its reversibility, removal and "correction." In other words, the epigenome, as dynamic and flexible unlike the genome, evokes hope that detrimental consequences of trauma may "not be there forever."

And yet, conceptually separating the "negative" consequences from the molecular memory of trauma appears to be an unresolved challenge. We could not see passed the politics and ideologies inherent to this kind trauma discourse, as clear in Alexander's point:

> AB: The good news is that if it's just epigenetic, it could be resolved. There's evidence from animals that by giving them enriching experiences and so- you know, I think revealing chips on your shoulder is useless. So I don't get into this, you know, let's blame past generations for this and for that, that's useless. I think what we need to learn from history in order to move forward is. . . and so epigenetics says yes, all the chips are real, but they're not there forever and with one dramatic change it could disappear. . .I'm not talking about erasing history, I'm talking about erasing the consequences.

These statements raise a number of significant ethical and conceptual conundrums for researchers in the field, including the ways in which one's "chips" are judged. Although these seemingly benevolent statements may give credence and "biolegitimacy" (Fassin, 2009) to notions of victimization through embodied trauma, they also draw a sharp and troubling line between "erasable" bodily consequences and external "past" histories. While epigenetics might hold explanatory and even emancipatory power, the pressing question of who, where and what are the violent agents is left wanting.

Attending to the means by which biological (and psychical) processes are relatively malleable, stable, sensitive and responsive opens space for social scientists to think about agents of other kinds, yet it also leaves us wondering how particular modes of violence can be discursively woven into neuroepigenetic analyses when they appear to be exclusively fixed on "purely" biological states. We wonder in particular how much the biological literalism of trauma, where its material truth takes life and validity through imprinted changes or abnormalities in the memory of cells and in the brain, contributes to a dangerous naturalization or reification that divorces trauma "from the complexities of people's lives and the social structures that give rise to them" (Burstow, 2003). The concern about a losing of complexity has been raised by anthropologists of science, who have pointed to the fact that, for instance in suicide studies, epigenetic notions of trauma are "treated as a black-boxed and dichotomous (i.e., present or not present) category, with the effects of varying experiences in differing contexts generally left undifferentiated" (Lloyd and Raikhel, 2018a,b: 501).

At the same time, we remain open to the idea that neurobiological and new neuroepigenetic evidence may "support 'what feminists [or other oppressed groups, our note] have known for a long time' about the effects of trauma" (Tseris, 2013), thus opening up a space for critical dialogue and contestation within biomedical knowledge (Herman, 2015). As Burstow (2003), it makes sense even from a radical stance to keep open a space of critique with "the term and concept [of trauma] nonetheless": not just because it is advocated by "injured people" or for its cross-cultural resonances but because the phenomenological experience of "soul wound" has a wider circulation particularly in postcolonial contexts (Duran and Duran, 1995; Pihama et al., 2014). More importantly, ceding it to biomedical reductionism is a disempowering gesture from the point of view of the wider social interests and awareness that the work of critique has paved.

[4] As Leys notices, "Trauma was originally the term for a surgical wound, conceived on the model of a rupture of the skin or protective envelope of the body resulting in a catastrophic global reaction in the entire organism. Yet as Laplanche has emphasized, it is not easy to retrace the "transposition" of this medicosurgical notion into psychology and psychiatry." (2000:19)

Akin to our interlocutors from feminist neuroscience (Roy, 2016; Fine et al., 2017), critical neuroscience (Choudhury and Slaby, 2011) and feminist STS (Haraway, 1988; Wilson, 2004), we believe that an analysis of difference (and sameness) on the scales of neurophysiology and sociality to be a vital progressive step, and one to be made with caution, care and a willingness to experiment with novel methodologies. What remains concerning, however, are the common-sense assumptions in regard sex and gender a number of epigenetic researchers expressed during interviews, which has also been illustrated in feminist STS scholarship (Kenney and Müller, 2017; Richardson, 2017; Saldaña-Tejeda, 2018; Warin and Hammarström, 2018). Importantly, we argue that whilst neuroepigenetic ideations may shed light on the ways in which trauma moves in, through and even out of the brain, we believe that epigenetics as a scientific culture needs to be held accountable for its own conceptual decisions, especially with regard to assertions about gender, race and class. We share the concern of feminist STS that pervasive and concerning notions of gender in epigenetic research need to be addressed, which we explore further.

STEREOTYPES AND THE "SOUND OF BIOLOGY"

In their engagement with epigenetic research, feminist STS scholars have raised concerns about the presence of problematic gendered narratives, tropes and stereotypes, particularly regarding human motherhood. In their article "Of Rats and Women" (Kenney and Müller, 2017: 23) argue that as epigenetic studies "support claims about human motherhood," they tend to "illustrate rather than interrogate existing stereotypes about maternal agency and responsibility." Along with Kenney and Müller's critique, other issues raised by feminist STS include: the exaggerated role of women in transmitting stress to her children and following generations; minimization of other socio-political agents involved in stress inheritance; the questionable use of animal models as a proxy for gauging human behavior; the role of epigeneticists themselves in reinforcing stereotypes of motherhood, particular in public debate (Richardson, 2015); and the potential risk of prospective health policies inherently burdening women with further care responsibilities and adding to already existing surveillance, especially of pregnant women (Richardson et al., 2014). On the one hand, epigenetics and neuroplasticity have been hailed as dissolving boundaries and dualisms, for instance between sex-gender and nature-nurture (Lock and Pálsson, 2016), while on the other, dualistic and essentializing ideas of biological difference remain in the vocabulary and design of epigenetic research.

While the gendered dimension of epigenetic studies has been robustly considered (Kenney and Müller, 2017; Richardson, 2017; Saldaña-Tejeda, 2018; Warin and Hammarström, 2018), and notions of trauma have been analyzed in the context of the epigenetics of suicide risk (Lloyd and Raikhel, 2018a,b), the ways in which gender and sex epistemologically underpin neuroepigenetic studies of trauma is yet to be investigated. To our knowledge, there have not yet been any feminist STS engagements at the intersection of sex, gender, epigenetic imprint and the nervous system; although we do not explore this in great depth here, it is important to highlight that this area requires further attention. Contributing to feminist STS studies on epigenetics, we find that despite the growth of research on paternal epigenetic transmission, the socio-political complexities of parental care and family life in human worlds – when diffracted through a gendered lens – are seldom addressed in neuroepigenetics. Herein, we support the notion that "new stories are old stories" (Kenney and Müller, 2017: 25), and in our case, stories relating to human paternity as well as maternity. Although our aim in this paper is not to offer a resolution or exhaustive critique *per se*, this is an important argument to be making here as we agree that sexism, misogyny and gender-based violence are very much connected to and couched in ambivalent, casual and seemingly harmless beliefs about gender and sex (Vecina and Piñuela, 2017; Testoni et al., 2019).

Many researchers who participated in interviews were - to varying degrees - aware of the issues raised by feminist STS, such as a disproportionate number of maternal studies in epigenetics, and how structural sexism may very well influence research designs, priority areas and funding. However, a substantial number of troubling assertions about sex and gender, as well as nature and nurture, were expressed by interviewees, all of whom were in relatively high positions of authority.

When asked about the disparity between paternal and maternal studies in epigenetics, neuroscientist and epigeneticist Thomas Lai (based at a neuroscience institute in Melbourne) explained:

> TL: Historically, medicine has been a very sexist sector, and we are still trying to overcome that. Even nowadays when I give my presentations and I make a passing comment that, hey, the literature is very skewed, we don't really study paternal effects, I don't think that that message actually sinks in, or they won't quite get it.

Lai was critical of the "skewed literature," yet he explained that there were legitimate reasons, such as: the ambiguous window of time to access sperm RNA prior to conception; technical challenges in breaching the sperm's casing; as well as difficulties securing the necessary funding for paternal studies. In response to the knowledge gap he saw, Lai has dedicated much of his career to paternal studies:

> TL: When it got down to the paternal studies, there was added motivation, because I went, hey, this is – it's stupid to think that, in terms of pregnancy and infant health, that everything should fall on the woman, that doesn't make sense at all. So, I thought that needed fixing.

Though for other researchers in epigenetics, the primary focus on "maternal care" in epigenetics is justifiable, given the particular figuration of evolution that is ingrained in human reproduction. During an interview with Alexander Berman, he described parental care-giving as considerably more of a genetic trait in female mammals, less so in males:

> AB: [Motherhood] is not something that happened this year right, it's quite old in evolution and it's built into the

> entire system, the way the brain is wired. When an animal becomes a mother, the whole brain is changing. It's a very strong thing. Humans learn to be fathers but it's more learned, it's less evolutionarily engrained, that's why you still have problems. So with all the politics and philosophy and changes in attitudes still [. . .] overall fathers would probably disappear more than mothers, and so you can take an animal model so far but in the end, I think evolution takes over and this is a big lesson.

A similar point was raised both by Adam Weber, a neuroscientist working on paternal epigenetic studies (Melbourne), and Connor Ringwood, who works in epigenetic tagging and brain development (Perth). For Adam, mothers are realistically the most influential on their offspring given their role in gestation, birthing and breastfeeding:

> AW: I wouldn't say there's an over-representation [of maternal studies], because the reality is, biologically the father. you know, passes on this genetic, and we think, epigenetic information at conception, and then all of the influence is pretty much with the mother, what she does during pregnancy, what she does while she's breastfeeding, early maternal care, obviously postnatally the father comes into play more, in mammals anyway, in some mammals like humans.

For others like Connor, given the particular reproductive role of mothers it makes sense that there is understandably more responsibility placed on them:

> CR: Well at the end of the day there has to be, there is naturally going to be more responsibility placed on the mother because they carry the next generations within them, whether blame should be exercised is a different matter, but if it's found that, we know there are behaviors that can have profound effects on the next generation, alcohol consumption for example, when that link is clearly made I think people then. it's much easier to rationalize and justify why certain behaviors need to change.

A particular figuration of human reproduction is inherent to these comments from Alexander, Adam and Conner; on the one hand, a mother's biology (in other words, her nature) readily changes in the process of childbearing and rearing, while fathers tend to naturally *stray*. And importantly, as Alexander went on to emphasize, these behavioral signs of evolution are, by virtue of their genetic imprint, slow to change. Yet the other hand, as he says, there is an urgency to "listen" to the sounds of evolution and biology:

> AB: Whatever political ideas we have, we do have to be attentive to the sounds of evolution and biology, right? There are some things that are going to be really hard to change if they're so deeply wired in our genome. This is not epigenetic, this is genetic, this is evolution.

A tension arises between what constitutes as "epigenetic" and "genetic" here, or to put in another way, between modes of evolutionary adaption inherent to human reproduction. While genetic and epigenetic dispositions here become seemingly synonymous with evolutionary accounts of nature and nurture respectively, we can't help but notice the unsettling authority of gene-centric doctrine raising its head (Haraway, 1976; Keller, 1997, 2002). What we find especially troubling in these framings is the kind of erasure they have the potential to cause. There is violence inherent to stereotyping (Dobash and Dobash, 1992; Butler, 1999; Gilbert, 2002) as much as there is potential harm inherent to trauma conceptions that downplay or are inadequately informed by knowledge of violence. In the somewhat idealistic representations of gender and gender roles illustrated above, there is a risk not only of lived and gendered experience falling out of the analytical picture, but of the finer "specificities of care" failing to receive the empirical attention they need (Mol et al., 2010: 9).

Drawing from the quotes above, they illustrate a need for biological scientists, and especially those in leadership positions, to be mindful of rehashing dogmatic evolutionary ideas about reproduction, familial care and gender roles. If neuroepigenetics provides a mouthpiece for neurobiology, and if biology's "voice" is akin to the sound of lived experience, might this not sound like gender politics, indeed, sound like politics in general? Rather than making old stories new stories, an attentiveness to the sounds of biology may in fact steer us toward legacies of embodied experience, as well as other agents and other ways of listening. Clearly, the issue of where and who agents are calls for cross-disciplinary dialogue, as it makes little sense to qualify a reactive genome and biologized environment when the epigenetic narrative reduces its own claims to questions of (mal)adaptive mothering and reason-able fathering. In the final section of this paper, we discuss some of the reasons for why collaboration is crucial now, and why social and biological scientists need to be talking to each other about matters of gender, trauma and embodiment.

THERE IS *SO* MUCH GOING ON IN REAL LIFE: COLLABORATIVE RESEARCH DIRECTIONS

After a number of attempts to strike a suitable time, one of us (EL-B) sat to a Zoom interview with Ian Tremblay, an epigeneticist and molecular biologist based in Melbourne. Before proceeding with the interview, Ian talked compassionately about some of the pandemic's many indirect victims: small business owners, international students, hospitality workers, elderly folk, and in particular, those surviving family violence. The daily news had rendered Ian melancholy, as he said:

> IT: I looked up a word "weltschmerz," it means "world-pain." It's kind of like, when you feel for the whole world. . . I think it affects everybody, there are layers of a dark heavy blanket over everyone.

In light of restrictions, curfews, isolation, financial hardship and other factors that have worsened in response to the pandemic, advocates have raised concerns about a rise in family

violence across the globe. As trauma psychologists [full name] (Kofman and Garfin, 2020: S199) have said:

> The novel coronavirus (SARS-CoV-2) and the associated disease it causes, COVID-19, have caused unprecedented social disruption. Due to sweeping stay-at-home orders across the United States and internationally, many victims and survivors of domestic violence (DV), now forced to be isolated with their abusers, run the risk of new or escalating violence.

Like other enduring and complex social issues, family violence has acquired a face in the pandemic. Yet, at least in Australia, statistics from the last ten years have been described as indicating a "national crisis" and "silent epidemic," with a third of women experiencing physical violence in their lifetime (Piper and Stevenson, 2019). Throughout the COVID-19 pandemic an array of social injustices have come to the forefront: low welfare payments, precarious casual workforces, racialized inequality and especially, the rates of family violence which overwhelmingly victimize women (Kofman and Garfin, 2020; Mazza et al., 2020; Fullagar and Pavlidis, 2021). We have argued in this paper that neuroepigenetics holds opportunity for creatively thinking about gender and gender-based harm as embodied (Blackman, 2011, 2016; Niewohner, 2015), yet the ways in which family and intimate violence eventuates at global, local and temporal scales pulls us into difficult interdisciplinary territory and exposes a rift between biological and social epistemologies.

During interviews, researchers themselves indicated a pervasive and at times frustrating issue with visibility (i.e., what can be seen) and invisibility (what remains hidden), and thus we do not wish to add unnecessary – and unhelpful – fuel to the fire. Yet, when neuroplasticity assumes environments, traumas and – in our case, genders – to be absorbable, the question presents itself of how we can hybridize and harmonize different methodologies in order to engage bodies, brains, modes of care and environments, without losing the finer nuances of these terms. As (Blackman, 2016: 269):

Epigenetics holds promise to qualify the relations between biology, psyche and trauma, yet paradoxically, it is also at risk of erasing the nuances of lived, embodied experience in its attempt to discursively molecularise the environment.

This point was especially salient in regard to one particular interview with neuroscientist Sasha Reed (Melbourne). At the time of our interview, Sasha was working with Serbian perinatal women who had experienced sexual trauma throughout the wars in Kosovo, a study which exemplified the trauma socio-political contexts can bring - quite literally - into life.

As Sasha explained, the aim of her project was to examine how epigenetic changes responsive to trauma may be passed onto the women's children. Though Sasha's research team were also interested in the kinds of supportive interventions available to survivors, such as social support and counseling, and how these may influence epigenetic modification. Sasha noted that many of the women using these services were doing so without their husband's knowledge; a reason being that sexual trauma was not to be talked about within their family unit. Unlike animal studies which are relatively much easier to control, this kind of local and human-based research proved challenging for Sasha's team; not only due to the substantially complex amount of agential factors requiring their consideration, but also because of the lack of control they had over the variables. This left Sasha feeling bereft, as she explained:

> SR: We are trying to do this kind of intergenerational research, but it's tricky I mean. It's very tricky. Just because there's so many other factors that you know you can't control. It's not an experiment. It's real life.

If there's one important point to be gained from Sasha's statement, it would help to return to a point we raised in this paper's introduction. In some ways, a feminist ethos has been innate to epigenetic research because of its decentering of DNA and heightened attention to contexts both internal and external to a cell's nucleus (Keller, 1988, 2002; Haraway, 2007; Malabou, 2010). In the example of Sasha's human-based research, the ways in which gender is lived, experienced, embodied and even inherited insists on epistemological and methodological attention. The team's position in relation to their research subjects matters, and we assume, to the degree of making methodological trouble. There is *so much* going on in "real life" – which we find to be a sobering realization that unsettles any clear divide between nature, nurture, biology and culture. Importantly, we believe that "real life" insists on taking pause to hear from and know about the people whose neuro-social narratives are being written, as well as how specific forms of violence may be illuminated or obscured by epistemological processes.

Perhaps a feminist ethos in this context – and indeed a feminist neuroepigenetics – could be to befriend ambiguity and use it as a touchstone for cross-disciplinary orientation. As hidden forms of violence persist – attached or not to civil war, famine or political unrest – neuroepigenetic methods are left wanting of other perspectives, and researchers themselves are pointing this out. Indeed, in many instances their accounts echoed the classic feminist catch phrase "the personal is political"; during an interview, one epigenetic researcher talked about an article he recently read about abusive relationships:

> IT: [It] was talking about these kinds of relationships, dependent relationships. I spoke to [the author] afterward because my niece-in-law is in one of those relationships with someone who's violent. And they keep going back, it seems to be one of those stories doesn't it, where it's, it's a common issue where it's some dependency. It's like the two people seem to go together, the abuser and the abused. It's not the fault of the abused, but it's just a known dynamic isn't it, I think, and you really feel, externally you – people go, why do you go back to that person? But it just, it just happens doesn't it?

Feminist STS theorist Donna Haraway (1988) writes that in knowledge-making endeavors, foregrounding social, political and environmental issues raises the risk of backgrounding others. When reflecting on "the

layers of a dark heavy blanket" Ian described, it raises concern about the invisibility, complexity and multiple scales of gender-based violence, and how such harms endure whether or not epistemological tools allow access. Historical epistemology makes us aware of the malleability of concepts and scientific tropes, as well as their open-ended political nature: even if rooted in a gendered imagination (for instance the figure of the hysterical woman in the nineteenth and early twentieth century: see Gilman et al., 1993; McDonald, 2018) or in premodern thought (the patriarchal assumption of female passivity in embryological processes on which marks can be left by the active power of the male semen), there is opportunity to model for wider processes of inscription and even trauma on memory (Lurz, 2008; Meloni, 2019). Feminist appropriations of trauma have occurred and are certainly possible (Brown, 2004) and similar work can be possibly done for its present neuroepigenetic iteration.

Although our goal here is not to provide a succinct roadmap for the kinds of collaborative research we hope will eventuate in this space, one practical suggestion we can make is a basic one: improve and increase communication. We say this because the process of interviewing epigenetic researchers was not a straightforward one. It took time for people to make the time to talk; it took them having time in the first place; and once the practicalities of working out time-zones and Zoom invitations were sorted, it took time to find common ground while mutually understanding the different methodologies and worldviews we have. It took many attempts to get the words right. Yet, we found that the most productive conversations were the most basic, honest and mutually understandable. They yielded rich dialogue, and moreover, a foundation to build "critical friendships" upon (Rose and Abi-Rached, 2013; Fitzgerald and Callard, 2015), which we are sure will prove to be fruitful and sustainable.

CONCLUSION

If epigenetics is indeed an opportunity to pinpoint moments where experience and biology meet, a useful question to ask, then, might be: if representations of biology, biological change and responsiveness can ethically account for environments, histories, politics and adversities, who and where are the agents we account for? As feminist STS scholars and medical anthropologists have shown, there is a necessity to turn toward a multiplicity of narratives, story and truth telling. This may help us to better grasp not a mono-objectivity of biology, but an objectivity that accounts for many perspectives (Haraway, 1988). In this paper, we have illustrated how epigenetics does indeed stand in complex relation to sex and gender, especially with regard to the kind of figurations of reproduction and inheritance. Yet we also find that neuroepigenetics offers a bounty of opportunity not only to consider biological and neurological agents in figurations of embodied trauma, but also to conceptualize gender as biologized. In regard to the prospect of collaborative research, our aim beyond this article is to foster cross-disciplinary discussions and gather together a plurality of voices, for instance by beginning with a neuroepigenetics and trauma online symposium. A useful model for this format is based on recent biosocial initiatives like the 2019 "Symposium on Biosocial Approach to Population Health Across the Life Course," hosted by the Carolina Population Center (CPC). The aim of this symposium was to:

> stimulate novel opportunities for biosocial health research by developing a scientific forum that provides emerging scholars a chance to present research, while facilitating the integration of social and biological approaches for addressing the complex health concerns of today[5].

Similarly, through a cross-disciplinary symposium that brings neuroepigenetic, feminist STS and medical anthropology into conversation, we see opportunity for novel biosocial approaches to trauma to be generated. We anticipate that the challenge of communication will surface when members of different camps arrive at the table. Thus, we suggest that the act of listening and respecting knowledge others arrive with to be essential. We understand some scientists do not want to enter into the gender-sex debate, or deal with so-called "semantics." If we may respond, we would say that unfortunately, this is not a chance we are given: for better or worse, all parties already have. For its entangled biosocial nature, epigenetics *does have* political traction and so each epistemological claim will be served best with cross-disciplinary discussion and accountability. We arrived at this project as students of epigenetic knowledge and have learned that trauma has no single ontology, even or perhaps above all in a standardized lab setting. One role of interdisciplinary discussion then is to unpack and unpick assumptions about gender in epigenetics, and to build generative methodologies that can engage with a plethora of agents.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Human Ethics Advisory Group (HEAG) – Deakin University. The participants provided their written informed consent to participate in this study. All identifying markers have been replaced with pseudonyms.

AUTHOR CONTRIBUTIONS

EL-B led the drafting of the article, and contributed excerpts from qualitative interviews conducted as part of her Ph.D.

[5]https://cpha.duke.edu/news-events/news/dupri-participates-cpc-symposium-biosocial-approaches-population-across-life

MM contributed a wealth of citations, material on the history and conceptualization of trauma, editorial suggestions, and provided support for the article's aims and focus. Both authors contributed to the article and approved the submitted version.

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PERSPECTIVE
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Reflections on Binary Sex/Gender Categorization in Magnetic Resonance Tomography and its Future Challenges

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This paper examines the role of technical, methodological conditions in functional magnetic imaging (fMRI) in the production of binary sex/gender differences. The aim is to investigate the scanning process with a focus on the statistical parameter of gendered markers within the technology, in order to make visible the problems entangled in typical research routines. It is especially important to elaborate this because the computer models currently being used and Big Data studies are reproducing and reapplying outdated and rigid concepts of sex/gender differences with the goal of improving science considerably. Therefore, the paper discusses the empirical methodologies and epistemic underpinnings of differentiation through statistics, and argues that counter-counting, weighing and sizing might not help to substantiate the idea of "equality" (not only for the sex/gender category) in brain studies. In relation to the topic of this special issue, I argue that in order to develop an interdisciplinary approach to criticizing dimorphism and differentiation by groups, a wider understanding of the technical and theoretical foundations used in brain research is needed.

Keywords: brain imaging, fMRI, sex/gender binary, interdiscipinary research, taxonomy, intersectionality

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INTRODUCTION

Before conducting my fieldwork in brain imaging labs, I assumed that the practice of gender categorization was set when the tomograph is programmed and that it directly affects the scanning process. I thought this mainly because, in practice, the first action of every scanning process is to set a marker: to indicate whether the person in the scanner is male or female. The third option, "neutral" is virtually never set when measuring human beings. It turned out that this specific moment in the scanning process is not when male/female markers become efficacious, or at least this moment does not necessarily inscribe the binary markers into the data. But of course, there is no such thing as "raw data". "Raw Data" is an oxymoron, as Lisa Gitelman (2013) reminds us: "Every discipline and disciplinary institution has its own norms and standards for the imagination of data, just as every field has its accepted methodologies and its evolved structures of practice". (Gitelman 2013, 3) Data is never just there, it needs to be generated, meaning that every object of investigation needs to be placed under a research issue and the assumptions of the method that is being used. In fMRI one of the most crucial underlying conditions is the concept of mapping, which falls into the tradition of categorization and specific thresholds plus values of normalization for groups. In fMRI most of the pre-processing and normalization steps are part of an "automated evaluation" built on digital atlases, which Anne Beaulieu has called "database diagnosis" (Beaulieu 2001, 664).

The preference for mapping and measuring differences in the brain has a long history. It has existed since the early days of brain research, when skull shapes were measured and rated by size and intelligence, as white, middle-class men were considered more intelligent than women and were also believed to be equipped with greater intelligence than was found in all other human groups and classes. This measurement of brains, or rather the mismeasurement of man (Gould 1996) led, given the doctrine of the normalization society, to standardizations and stereotypes. However, at all times there was also a critique of biological sex dimorphism, hierarchization and essentialism. Take, for example, the feminist (or suffragette, the term used in the 1880s) Helen H. (Gardener, 1887). (1853–1925) and her conviction that young girls "brains were conditioned in the same way as boys", and therefore girls should have the same access to education. In her paper "Sex and brain weight" (1887) Gardener argued that no connection between brain weight and intellectual capacity had been proven, and she thus challenged the prevailing methodology for measuring brain size. Gardener's approach to asserting the equality of male and female brains was based on the assumption that it was not the comparison that was problematic, but rather the basis of the comparison, and in her view this meant that brains from the same "race"[1] and the same class perform equally. This idea of an "evolutionary ladder" was also part of Gardener's approach. In her understanding not all women were equal, but some woman were more equal to well-educated white men than others. "The idea that brains could be raced and classed, as well as sexed, would have appealed to Gardener, too; for in many ways what she and Stanton hoped to do was align themselves with their elite white male peers and distance themselves from poor women, female immigrants, and women of color" (Hamlin 2007, 153).

The example of Gardener's nineteenth-century work shows that to succeed with an interdisciplinary and intersectional critique, it is not enough to take issue with the results of empirical methods such as weighing, sizing and mapping alone. Gardener's story warns us of the dangers of explicitly making only sex/gender difference a subject of discussion, as brain science may also discriminate against the brain of the "other". In this sense neuroscience today should realize that the concept of innate differences in the brain's anatomy and brain performance (meaning intelligence) persists, while the (measurement) methods are constantly changing (Staub 2018; Eliot et al., 2021). Today we can observe a rise of statistical and stochastic approaches in brain modelling neuroscience. In order to understand these new methods of empirical measurement and categorization, it is crucial to examine the idea behind these methods and the claim that predictions can be based on the assumptions related to the categories and types employed. Therefore, it is necessary to understand the underlying techniques as well as the empirical statistical process in functional imaging (Fitsch and Friedrich 2018).

TECHNICAL PRACTICES OF DIFFERENCE

In the last few years many scholars have critically investigated the concept of sex/gender research in neuroscience (Bluhm et al., 2012; Kraus 2012; Fine et al., 2013; Schmitz and Höppner 2014; Joel and Fausto-Sterling 2016; Grissom and Reyes 2018; Fausto-Sterling 2019). Nevertheless, in order to address the question of the stage at which sex/gender comes into brain imaging, I will describe the technical conditions in the following. Even though the scanning process itself is not directly linked to sex/gender markers, I want to point to multiple other techniques that inject sex/gender difference into fMRI research. I therefore look at the idea of differentiation that is embedded in the brain imaging method and can be found in the question of the study design, the statistics and the interpretation of the data.

The Scanning Process

FMRI, as the term suggests, is an imaging method. Imaging procedures are characterized by the fact that they do not translate an original relatum into an image; rather, the technique visualizes a process which simultaneously produces a phenomenon in the first place. The elaborately generated images are the result of an indirect procedure and not, like photography, the depiction of something existing[2]. Brain imaging techniques transform the material brain into a visual medium (Balsamo 1999, 223) by measuring the BOLD signal, which is dependent on the blood oxygenation level and the magnetic susceptibility changes caused by fluctuations in the local oxygen concentration. "It is a direct measurement of the dephasing of spins of water molecules in blood, caused by local differences in magnetic susceptibility. Increased levels of deoxyhemoglobin reduce the BOLD signal; reduced concentrations increase it". (Roskies 2008, 23).

The technical procedure of fMRI entails the recording of magnetic resonance signals to provide information about specific physical properties of the protons in the brain at a specific location. By changing the physical properties due to biological effects (oxygenation, flow), different local signal intensities are measured under different stimulation conditions and evaluated using statistical methods (t-test, General Linear Model). However, the acquisition of MR images is a non-invasive process that receives signals from the hydrogen protons inside the body through the temporal sequence of magnetic and radio frequency field changes. Subject-specific information is not required, either for the measurement or for the evaluation of the data. At this point in the measurement process the MRI scanner does not evaluate or compare the data, but converts the signals of the hydrogen protons into a digital image. As this happens, certain principles (such as Fourier coding) are exploited. The spatialized voxels are assigned one of 4,095 grey values for the

[1]I place "race" in quotation marks, as I truly believe that the category of "race" was invented by scientists to scientifically differentiate humans in a racialized way, which led to racism as it continues to exist today. At the same time the category "race" is necessary to describe the continuities and effects of racism, which are inscribed in the structure of contemporary societies. For further thoughts on the question of "race" in sociology, see the racial formation theory proposed by Michael Omi and Howard Winant (Omi and Winant, 1994).

[2]This does not mean that the constructive character of other media such as photography, film, etc. should be denied.

display, which at the same time indicate the activity value of the signal measured there. The scanner is calibrated once on a water phantom, so that no intensity comes out that lies above the scalable range. FMRI produces pure intensity images, meaning that a relative signal is measured rather than an absolute one. It is not important whether the intensity is 900 or 1,100, as long as the other quantities are "in relation". Since the MR system is a medical diagnostic device, it is possible to enter name, date of birth, sex, weight, height and other information so that a patient can be uniquely identified at a later point in time. Weight is the only information that matters for the tomograph, as it is taken into account to determine the high-frequency radiation deposition in order to prevent harm to the person in the scanner. We should not forget that fMRI has been widely critiqued for the significance it gives to showing "brain activity". For example, the blood vessels measured for minimal signal changes account for only three percent of a given voxel in the brain (Müller-Jung 2008, N1). In addition, the temporal resolution is very poor: the canonical notion of an optimal BOLD signal assumes neuronal activity that occurs 4–10 s after stimulus exposure (Fitsch, 2012, 282).

Normalization and Pre-Processing in fMRI

After the scanning process, the data need to be prepared for further analysis and interpretation. Since the measurable signal effect is minor, regions of interest have already been defined in the study design, and the focus will then be placed on these regions in the further evaluation process. Then statistics and standardization come into play: statistical corrections of the data such as noise reduction, correlation analysis, t-test, temporal characteristics of the signal changes (hemodynamic response function); in addition, systemic contaminations that come within a magnetic resonance scanner such as signal drift. Other influencing variables, such as distortions or head movement, are also corrected by using algorithms. To better suppress false positive activations smoothing and clustering methods are used, as well as corrections for multiple comparisons. All of these pre-processing steps refer to statistical standardizations used to prepare the data for analysis. The activation patterns are brought into the form of cartographic representations to identify the areas where a signal change occurred, and these can then be subtracted from each other. Subtractions are used to isolate elements of cognitive processing and generate results by accentuating the differences in the data (Fitsch, 2012).

Normalization in fMRI describes the adjustment of single brains to a stereotactic coordinate system such as Talairach, or MNI, in order to compare the data in the further analysis. The Talairachian reference system is based exclusively on the measurement of the brain of only one woman. For the process of analysis, only one pattern of a region of interest (ROI) is created to avoid single brain fitting, and therefore the brain anatomy has to be aligned to a standard brain to ensure the probability that in each brain the regions of interest are found in the same position (Jäncke 2005). Therefore, not only every single item of anatomical brain data is adjusted to a standardized brain; in addition, the functional data needs to be "normalized" to superimpose the functional data onto the anatomical brain map. In imaging, normalization describes the approximation to stereotactic coordinates and the spatial co-registration of the functional to the anatomical data. Normalization describes the steps in which various brains are matched to a norm brain in order to compare the data obtained from the different subjects. Here "size" becomes a not unimportant parameter in the normalization process: it matters and does not matter at the same time. Size is not an indication of intelligence or thinking activity. But "from the beginning, the search for such sexual dimorphisms in the human brain has been faced with a scaling problem. Recognizing that brain size is related to body size and because human bodies are indeed quite different in size, neuroscientists have had to find ways of comparing brain structures between men and women that won't merely reflect overall body size" (Eliot et al., 2021, 670). To negate these differences in brain size, which correlate with body and head size and have nothing to do with the individual quality of cognitive performance, "normalizing these measures to individual brain or head size largely eliminates any volume difference between males and females in specific structures" (Eliot et al., 2021, 688).

Initially the default setting has no influence on the further scan procedure, but the individual markers like women/men are nearly always used in fMRI studies even if the option of clicking the checkbox "neutral" is available. This general binary categorization of subjects is highly problematic, as it can be used as a "free category" in your analysis; if you don't find anything significant in your data, you can still find a publishable finding on gender difference, including false positives, with no further cost for the researchers or any need to collect more data (Bryant et al., 2019). Data analysis in fMRI analysis is based on group comparisons subtracted from each other to find more or less activity in regions of interest. And as the data are already marked in two categories, they can be compared with each other. Every single step to prepare the data for further analysis to make the data comparable is gendered. There is a firmly inscribed male, hetero, white norm here that cannot be easily undermined.

Imaging methods have changed in the last ten years, due to technological developments and especially due to the increasing computing power of computer processors. Following the epistemic alteration from brains as stimulus-response processing systems to brains as prediction machines (Clark 2013), new statistics and the method of computer modelling have become crucial in neuroscience. These computer modelling and machine learning methods are currently being added to established techniques such as functional imaging (Mahfoud et al., 2017). Machine learning is primarily a scoring system that scores the probability of the most likely event (O'Neil 2016), where data "becomes destiny" (Gelman 2018). Modelling has its own epistemological pitfalls, which are different from those of imaging. Yet today less criticism is being directed at the drawbacks of fMRI, such as the stereotactical mapping of behavior and the production of differences through grouping and comparing data, so that data from fMRI studies are being used without being questioned in order to model further with machine learning or Big Data studies.

DISCUSSION

At the same time as Gardener was writing about brains and education, Anténor (Firmin, 1885) (1850–1911) put forward a

fundamental epistemic critique of specific methods for classifying the brain in anthropology. Firmin published his book on the "Equality of Human Races", *De l'égalité des races humaines: Anthropologie positive*, in 1885. In this work he challenged the racialist anthropometry and craniometry, and racist interpretations of human physical data, of his time. Firmin explicitly criticized the methods of scholars like Paul Broca, who were creating scientific racism using numeric, craniometric tables that showed alleged differences in size and established a white superiority. Reading Gardener together with Firmin's critique shows in an exemplary way that it is not enough to criticize the gendered results of a so-called empirical method of weighing, sizing and mapping; we also need to look closely at the epistemic ideas behind these methods and to develop multivariate concepts of the brain and its social embeddedness, and of its dependence not only on intra-individual processes but also on intersectional and interpersonal interactions.

Today fMRI data is often analyzed using Big Data and machine learning methods. As Neurofeminism scholars, we can ask how Big Data studies and deep learning can also be helpful in the search for unknown correlates and connections. But as statistics is all about learning from data (Gelman 2018), and statisticians are looking for unexpected patterns using mathematical modelling and data visualizations, one has to be aware of which data are being used to learn from. "The problem of the foundation of statistics is to state a set of principles which entail the validity of all correct statistical inference, and which do not imply that any fallacious inference is valid. But most statistical inference is concerned with a special kind of physical property" (Hacking 1964, 1) Statistical methods become evident in differentiation studies, as the main problem remains: that scientists are still asking the same old question of sex/gender difference (Bluhm 2013; Rippon et al., 2014) and "Why Do We Think Racially?" (Machery and Faucher, 2005; Heinz et al., 2014). Asking about differences, and yet again not only about sex/gender differences but also about "race", class, and ability differences between brain performances, can be described as a bio-political statement as "it is not driven by new research findings but rather by a priori certainty of the existence of sexed/gendered difference and the heteronormative complementarity inscribed in the very foundations of our society" (Fitsch et al., 2020, 53) This is also true for the categories of "race" and class, and while innovative brain technologies have been prioritized, "the development of innovative brain technologies, perfunctory applications of seemingly objective research tools contribute to structural racism. Thus, neuroscience will benefit from a critical introspection that reassesses existing modalities, techniques, and ontologies retained and relied upon to measure and visualize the brain" (Rollins 2021, 1).

For an interdisciplinary, and perhaps even intersectional, approach to differentiation through brain imaging it is crucial to be aware of the complex technical aspects of neuroimaging research, as they convey the methodological implements for the interpretation of the data. And at the same time, another concept of difference is needed: "The issue here is not only the politics of measure as such, but also the politics of meaning. Our engagements with the neurosciences must therefore begin with the question of how we bring forth difference, and this in itself is the beginning of an ethical response" (Roy 2012, 229) So for a future perspective two issues have to be taken into account. On the one hand, we need to understand the historically implemented concept of "difference" in mathematical calculations and statistical models. And on the other hand, we need to appreciate how these concepts of difference (sex, gender, class, and "race") are intersectionally intertwined with each other. For interdisciplinary or rather intersectional approaches, we need to ask to what extent the categories of "race" or class have found their way into the statistical measurement strategies of contemporary brain research (Abiodun 2019; Birhane and Guest 2020; Rollins 2021).

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

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

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Reflections on Neurofeminism and Intersectionality Using Insights From Psychology

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Intersectionality contends that sex/gender is constituted of and with other social categories, and that the social structures giving rise to inequality should be addressed in research. This is a powerful and important perspective from which to investigate the processes and consequences of social group memberships, one which has been overlooked by most neuroscientific research. In particular, neurofeminism, a field of critical neuroscience that challenges neuroscientific assumptions, methods and interpretations of data that reinforce sexism, has ignored intersectionality to date. In contrast, research in the field of psychology has been engaging with intersectionality for more than a decade. In reflecting on how intersectionality has advanced feminist research in psychology, this paper provides a critical analysis of potential novel research avenues for neurofeminism. We identify three main research themes guided by intersectionality. The first theme involves research centered on understanding the *socio-structural causes* of health inequalities experienced by individuals with intersecting marginalized social identities; the second concerns research addressing the *psychological processing of social group memberships* that underlies the enactment of systemic discriminatory practices; and the third theme comprises intersectionality research that aims to challenge *psychological epistemology*. Drawing parallels between the fields of psychology and neuroscience, we explore the potential benefits and risks of advancing an intersectionality-informed neurofeminism.

Keywords: sex/gender, neuroscience, feminism, intersectionality, psychology, epistemology, social structures, social justice

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INTRODUCTION

Neurofeminism is the feminist practice and criticism of neuroscience. Neurofeminists challenge research practices, including assumptions, methods, and interpretations of data that reinforce sexism by treating neuroscientific knowledge as acultural, apolitical, and sexually dichotomic (Kuria and Hess, 2011; Bluhm et al., 2012; Schmitz and Hoppner, 2014). To overcome the flaws of traditional

sex/gender[1] neuroscience, neurofeminist work has developed alternative conceptual (e.g., the mosaic brain, Joel, 2011; Joel et al., 2015) and methodological (e.g., brain size correction, Rippon et al., 2014; Sanchis-Segura et al., 2020) neuroscientific approaches to studying sex/gender. These contributions highlight the context of neuroscience as a discipline (Fine, 2010; Roy, 2012; Jordan-Young and Karkazis, 2019), recognize the constraining role of sexed/gendered experiences in shaping sex/gender development (Fausto-Sterling, 2021), address the role of sex/gender in brain structure and function (Eliot, 2011), and understand sex and gender as fundamentally intertwined (Kaiser, 2012). One important contribution of neurofeminism to date has been to expose methodological and conceptual biases within neuroscientific research postulating that sex/gender differences in behavior are fundamental and caused by "hard-wired" dissimilarities between women's and men's brains (Fine, 2012; Joel and Vikhanski, 2019; Jordan-Young and Karkazis, 2019; Rippon, 2019; Eliot et al., 2021). Another important contribution has been the demonstration that certain sexed/gendered *behaviors*, irrespective of assigned sex/gender at birth, can induce hormonal change (e.g., aggressive behavior increases testosterone, nurturing behavior decreases testosterone; van Anders and Gray, 2015) reinforcing the notion that sex-based biological differences, if any, are influenced by socio-cultural differences such as behavioral expression. Finally, neurofeminists have provided numerous recommendations related to the epistemological assumptions, language use, postcolonial constraints, and the categories and research methods employed to conduct sex/gender-related neuroscientific investigations (Einstein, 2012; Kuria, 2014; Rippon et al., 2014; Roy, 2018; Duchesne et al., 2020).

Despite these successes, the feminist approach to sex/gender-related neuroscientific research remains in the margins of the field, particularly since national funding agencies have incentivized sex-segregated biological research (as discussed in Eliot and Richardson, 2016; Joel and McCarthy, 2017; Gungor et al., 2019). For instance, in 2016, the National Institute of Health started requiring awardees to account for sex as a biological variable (SABV) in all stages of their research (design, analysis, and reporting) in vertebrate animals and humans (National Institutes of Health (NIH)., 2015). Currently, calls for SABV-based neuroscience abound (e.g., Bale and Epperson, 2017; Bath, 2020; Bhargava et al., 2021; Shansky and Murphy, 2021). In recent years, an increasing number of feminist scholars have advocated for bioscience researchers to engage with intersectionality as a theoretical framework[2] that could aid in generating socially contextualized and reflective biological knowledge, and provide a counternarrative to other essentializing and risk-oriented explanations in biomedicine (for a review, Hankivsky et al., 2017; DeBlaere et al., 2018; Shattuck-Heidorn and Richardson, 2019; Jacke and Palm, 2020). However, to date, intersectionality remains largely overlooked in the design, analysis, and interpretation of sex/gender-related neuroscientific research. As this special topic aims to advance the development of critical investigative approaches in sex/gender and the brain that are grounded in plurality, we explore whether and how intersectionality can provide novel research avenues for neuroscience, and in particular, for neurofeminism.

Rooted in Black feminist activism, intersectionality as a theoretical framework states that sex/gender is constituted of and with other discriminatory social categories (Shields, 2008; DeBlaere et al., 2018; Mays and Ghavami, 2018). First articulated in qualitative legal research to deconstruct the sexed/gendered experiences of African American women (Crenshaw, 1989, 1990), intersectionality as a theoretical framework currently informs research across several disciplines that investigate various processes involved in experiences of social injustice emerging from intersecting group memberships (e.g., De Vita et al., 2016). For more than a decade, sex/gender research in psychology has been informed by intersectionality (Shields, 2008). As this literature grows there has been much debate as to which conceptual (McCormick-Huhn et al., 2019), methodological (Else-Quest et al., 2006; Bowleg and Bauer, 2016; Scott and Siltanen, 2017), and epistemological (Warner et al., 2016) approaches to conducting psychological research best align with an intersectionality framework.

The current field of sex/gender-related neuroscientific study is largely uninformed by an intersectionality perspective, treating sex/gender as a category orthogonal to other social group memberships. Adopting an intersectional approach means adopting a commitment to understanding the interdependence of social group memberships beyond conventional factorial interactive analyzes of interdependence of social group memberships. In this paper, we draw from a breadth of psychological research to explore potential benefits and risks of using intersectionality in neuroscience. Specifically, we identify three psychological research themes that differ both in their use of intersectionality, and in the domain of psychology under investigation. The first approach to employing intersectionality in psychological research focuses on understanding *the socio-structural causes of health inequalities* in individuals with intersecting marginalized social identities. The second approach uses intersectionality to interrogate the *psychological processing*

[1]For decades, empirical and theoretical evidence has shown that biological "sex" cannot be empirically disentangled from "gender" due to the complex embeddedness of these constructs (e.g., Haraway, 1992; Butler, 1993; Fausto-Sterling, 2000). Not only are these two constructs entangled, the generic use of each for describing a "biological" versus a "social" phenomenon instead of using the actual biological measure of the social construct, is unscientific. In other words, using "sex" instead of, for instance, "estradiol" or using "gender" instead of, for instance, "gendered attitude" has become far too unprecise based on the knowledge that gender studies and biology have provided. Thus, using "sex" and "gender" separately perpetuates, terminologically and epistemologically, a duality which, first, is not a clear-cut binary and, second, is conceptually erroneous given the diversity captured within and across these terms. In the present analysis we employ the hybrid term sex/gender (Fausto-Sterling, 2012; Kaiser, 2012; Schellenberg and Kaiser, 2018) to describe this embeddedness and overcome the apparent dichotomy. Importantly, the use of sex/gender as a hybrid term is not to be interpreted as an argument that "sex" and "gender" are reducible to the same thing. To suggest that "sex" and "gender" are reducible to the same thing would certainly be counter to any notion of an "intersection" between the two.

[2]A theoretical framework is defined as a theory that can support the development of other theories, methods, and research questions (Imenda, 2014). Similar to Else-Quest and Hyde (2016a), we refer to intersectionality as a series of assumptions/principles and commitments comprising a theoretical *framework* that can be employed to inform research and knowledge production more broadly, rather than as a falsifiable theory (Else-Quest and Hyde, 2016a).

of social group memberships that underlies the enactment of systemic discriminatory practices. Finally, the third approach employs intersectionality to interrogate how psychological knowledge is produced and understood, and in doing so, *challenges psychological epistemology*. Each research theme will be compared with neuroscientific research informed by intersectionality, if any.

RESEARCH THEME #1: HOW SOCIAL STRUCTURES CREATE HEALTH INEQUALITY IN INDIVIDUALS WITH INTERSECTING SOCIAL IDENTITIES

One theme of psychological research informed by intersectionality focuses on delineating the social structures responsible for health inequities experienced by individuals with marginalized intersecting social identities. Social structures are defined as the social layouts of a society that arise from and subsequently constrain people's actions, resulting in the categorization of individuals in groups through normative sets of roles, functions, meaning, purpose, and power dynamics (Haslanger, 2016). Socio-structural factors are a source of influence at all levels of society, including laws, policies and practices, economic characteristics, occupations, and familial organization. Psychological research conducted with the goals of (1) exposing the complexity of oppressive social structures related to group membership and (2) understanding the health ramifications of such structures, uses varied quantitative and qualitative methodologies. Such research is centered on populations that are often hidden from major analysis and health inequality frameworks, and avoids notions of simplistic, additive social categorization (e.g., categorizing people by race, class, or sex/gender) by conceptualizing social group membership categories as *interdependent* rather than independent (Bowleg, 2008; Warner, 2008). Importantly, the interpretation of research findings within this approach is oriented toward concrete action for social change and justice. In sum, this type of psychological research employs intersectionality to guide the development of the research problem, the selection of methods, the study population and the data interpretation, in order to produce psychological knowledge about health inequalities that is contextualized within an understanding of oppressive socio-structural power dynamics, with the goal of dismantling them (Bowleg, 2008).

A recent publication by Kteily-Hawa et al. (2019), highlights the importance of this type of research for elucidating complex interactions between social categories in relation to health outcomes (Kteily-Hawa et al., 2019). This study investigated how oppressive social structures associated with immigration experiences increase health vulnerability in South-Asian women living with HIV in Canada. The authors conducted interviews and thematic analyzes focused on how power relations, emotional relations, social norms and sexed/gendered divisions of labor intersect to create a unique context that increases the risk of HIV (Kteily-Hawa et al., 2019). Their findings revealed that sexed/gendered roles within the household reinforced male control over the division of labor at home, and that these dynamics were in turn reinforced by immigration experience. Similarly, English et al. (2020) investigated socio-structural factors related to psychological health and health behavior outcomes within HIV-positive, Black sexual minority men (SMM), and demonstrated how history of incarceration, recent police arrest, and experiences of discrimination by police and other law enforcement interact to predict sexual behaviors related to HIV risk, psychological distress, and the motivation to seek prophylactic treatment (English et al., 2020). As highlighted by the authors, the unique carceral and law enforcement experiences and health correlates of Black SMM, a population at increased risk of incarceration in the United States, are often overlooked when their data are aggregated with those of Black heterosexual men or White SMM, rendering Black SMM an intersectionally invisible population. This study revealed negative health consequences of experiences with law enforcement for the Black SMM community in demonstrating that prior incarceration history, police and law enforcement discrimination, and recent arrest all showed direct and indirect relationships to worse psychological health outcomes. By exposing the socio-structural factors associated with health inequality within certain group memberships, this type of intersectionality research provides an understanding of health that is directly linked to power dynamics, and offers an approach to studying health and wellness that has the capacity to promote social change.

Importantly, this type of intersectionality research differs meaningfully from research that focuses on health outcomes *as a function of* broad, decontextualized social categories. Labeled "flattened" intersectionality, this latter type of research tends to explore the interaction between broad social categories (e.g., sex/gender, race, and class) without any assessment of socio-structural or other contextual factors (e.g., discrimination), or in other words, treats social categories as fixed determinants outside of their socio-historical oppressive context (Warner et al., 2016), and thus avoids dealing with the "latent" issue of inherent socio-structural power relations. In using a "flattened" approach to intersectionality, the focus of the explanation becomes the individual. This shift in focus occurs at the expense of interrogating and ultimately dismantling the socio-structural power imbalances that underlie health inequality. By decontextualizing social categories from their socio-political structures, flattened intersectionality research leaves room for essentialist explanations (e.g., social selection explanation, Mackenbach, 2005), and with that, the possibility of reinforcing oppressive structures through ignoring, and thereby masking, their contribution to a psychological or other health-related phenomenon (examples reviewed in Buchanan and Wiklund, 2021). As recently described by Buchanan and Wiklund (2021), flattened intersectionality comprises a large portion of contemporary intersectionality research in psychology, which the authors attribute to exclusionary epistemic practices by "mainstream psychology" (epistemology is further discussed in section III; Buchanan and Wiklund, 2021). In contrast, intersectionality research that works to understand the complex socio-structural liberative and oppressive contexts of social

group memberships moves away from broad categories and individual-centered explanations by explicitly positioning the roots of health inequality within social systems.

Neuroscientific research that studies the neural ramifications of health inequalities tends to focus analysis on a single group membership. For instance, the neural correlates of social class, or more specifically of poverty, are commonly investigated in neuroscience. Such studies have documented numerous associations between socioeconomic status (SES) and the function and structure of the developing brain (Hackman and Farah, 2009; McDermott et al., 2019). However, while this research characterizes brain correlates of oppressive economic conditions, it does not consider the social experiences and consequences of poverty as interdependently related to other social group memberships, and tends to "detach" material poverty from its oppressive socio-political context. Like the flattened intersectionality research described above, this kind of neuroscientific research inadvertently promotes essentialist and deterministic interpretations of brain data. This apparent paradox has been explored in a recent publication by Pitts-Taylor (2019): "most of the studies I reviewed propose that the effects of social inequality can become entrenched in the brain, shaping future neurobiological, cognitive, and even socioeconomic trajectories. In other words, they reify and 'fix' the phenotype" (Pitts-Taylor, 2019). Without accounting for socio-structural factors, researchers risk reinforcing the view that poverty persists due to cognitive "inferiority" rather than as a complex outcome arising from numerous avenues of social inequality.

To date, we are aware of one neuroscientific study examining the role of socio-structural context within a population characterized by multiple marginalized group memberships. Thames et al. (2018) demonstrate that the reported experiences of social adversities (racial/ethnic discrimination and childhood SES) corresponded with both structural brain differences and worse learning and memory performance (Thames et al., 2018). While this study broadly focused on different types of social adversity, its findings also captured how, in HIV-positive populations, the intersection of race- and class-based structural oppression is associated with neural and cognitive impairments. In their critical analysis of neuroscience, neurofeminists have emphasized that critical race analysis must be considered in any investigation aiming to understand and ultimately dismantle inequitable sexed/gendered conditions (Roy, 2012; Kuria, 2014; Rippon et al., 2014), and as our discussion highlights, research in neuroscience that is informed by intersectionality must expand its focus beyond sex/gender and race to include a wider spectrum of intersecting and marginalized identities. With the exception of a recent pain study conducted with Somali-Canadian women with female genital cutting (further detailed below, Perovic et al., 2021), to date, there are no neurofeminist parallels to this type of research (Fitsch et al., 2020).

In light of these observations, how can intersectionality advance neurofeminist work? First, explicitly approaching sex/gender as interdependently constituted of and with other social group memberships is a critical area for advancement. Second, increased focus should be placed on conducting research with populations of women and sex/gender diverse people that, because of their marginalized group memberships, are often rendered invisible. However, as mentioned, research that addresses intersectionality only at the level of individual identity is severely lacking and risks reinforcing oppressive social structures through ignoring the impact of these structures on health. It is critical for neurofeminists to formulate *how* specific socio-structural power dynamics may contribute to or fully explain previously observed sex/gender-related brain health inequalities. Only after identifying these socio-structural dynamics can researchers begin transforming these socio-structural factors, policies and practices, occupations, laws, familial organization, racial minority status, and economic characteristics into operationalized measures that can be incorporated into neuroscientific research designs. This is a foundational step toward advancing neurofeminism, and requires going beyond what has been articulated in neuroscience to date. Finally, researchers must consider selecting methodologies and analytical approaches that allow for the socio-historical contextualization of oppression and privilege (discussed further in section III). Sex/gender neuroscience research guided by intersectionality as articulated in this section will further contribute to understanding health outcomes contextually rather than centering on individual, deterministic risk factors.

In this section, we considered the importance of intersectionality as a framework for understanding outcomes related to health inequality as complex, contextualized phenomena arising in part from oppressive socio-structural power imbalance rather than individual risk alone. In the following section, we explore research that interrogates the psychological processes by which socio-structural oppressive attitudes and behaviors may arise.

RESEARCH THEME #2: HOW INDIVIDUALS PROCESS INTERSECTING SOCIAL IDENTITIES

How do people process and understand information related to intersecting social categories? A second theme of psychological research informed by intersectionality relies on quantitative methodologies to provide an understanding of how information-processing related to different social categories may underlie processes of social discrimination. Primarily, this research theme focuses on representation of intersected social identities at the level of the stimulus bank of a study, and less on representation within a participant sample. In other words, this type of psychological research employs intersectionality to guide the development of the research question, while relying on traditional psychological approaches to study design, analysis, and interpretation of data.

Prior to the integration of intersectionality in psychology, psychological research examined racialized or sexed/gendered variables as independent stimulus categories. Using this type of categorization, abundant work exists on what was first called "race recognition" and later "racial bias" research, in which the

aim was to measure the relative contributions of automatic (i.e., unconscious or unintentional) and controlled (i.e., conscious or deliberate) processing to a racialized phenomenon of study (Dasgupta and Greenwald, 2001). The assumption of much of this research (and indeed, of psychological science broadly) is to understand "fundamental" processes, and as such, the universality of these processes across individuals is often implicitly assumed. Such hidden assumptions of universality are reflected in the overwhelmingly common use of homogeneously Western Educated Industrialized Rich Democrats participant samples. Despite its possible contributions to our understanding of the psychological processes underlying discrimination, this approach of investigating how psychological processes and experience can be understood "in general" without regard to socio-structural context leads to research findings that partially bind results to a normative population and support the unequal power dynamics of existing societal structures through the uncritical reproduction of the dominant normative perspective.

Early research within this theme investigated the interacting effects of processing sex/gender and racial information using pictures of faces, again often through factorial designs in which categories are treated independently. In a seminal study by Goff et al. (2008), participants were presented with Black and White female and male faces. Results revealed a sex/gender categorization bias for stimuli depicting Black persons such that the perceivers judged both Black men and Black women as more masculine than White counterparts. Further, faces depicting Black women were rated as less attractive than White women, an effect that was mediated by ratings of masculinity. Numerous studies in face-based judgments have since expanded these findings by varying the racialization of the stimuli (Johnson et al., 2012; Hopper et al., 2014), the study's target population, and age of participants being studied (Kim et al., 2015; Li and Tse, 2016; Lei et al., 2020). Importantly, the results of Goff et al. clearly expose a research bias toward white women in sex/gender-related social cognition research, based on a white majority (82%) of participants, as well as the erasure of Black women exemplified in Stolier et al.'s face stimuli visualization (2017), see **Figure 1**. This bias in the conduct and presentation of the research itself highlights a pressing need for psychology to begin operating within a theoretical framework that conceptualizes the perception of sex/gender as a process encompassing plurality contingent upon other social realities (Goff and Kahn, 2013).

Currently, this type of psychological research is seeing a development of novel methods that aim to integrate how social group memberships are processed and experienced. For instance, novel multiracial faces databases are being created, reflecting both the impact of intersectionality in the psychology and cognitive human neuroscience of face processing (Chaney et al., 2020; Chen et al., 2021) and the consequences of diversification in psychological samples. That said, the mere diversification of stimulus banks and participant samples does not address socio-structural power dynamics; what is considered "masculine" and what is considered "attractive," are strongly informed by the socio-structural power dynamics that are commonly overlooked in these kinds of studies, which results in research that merely summarizes descriptively the very processes of discrimination for which it attempts to elucidate psychological mechanisms.

Alternatively, an increasing number of experimental studies use intersectionality to investigate the psychological processes at play in the experience (rather than perception) of intersecting social identities. For instance, in a study investigating how participants' own sex/gender and race relate to perceived safety and threat cues in Black, Latina and white women, Chaney et al. (2020) demonstrated the transferability of threat, but also safety cues, from the racial to the sex/gender category – meaning, for instance, that Black and Latina women anticipated both racial and sex/gender discrimination from an identity threat stimulus that was designed to target only one of their stigmatized identity categories (Chaney et al., 2020). Similarly, when presented with an identity safety cue, the safety experienced in relation to one category is transferred onto the other category. By demonstrating at the psychological level how intersecting marginalized social identities confer disadvantage and advantage (e.g., experience of threat or safety) depending on the social situation, this research exposes the ramifications of power imbalance in social inequality. Taken together, these findings provide evidence and novel tools for an increased representation of the diversity of social group membership (e.g., databases), and even form the basis for potential, direct improvement of social interventions and advocacy policies.

Concerning neuroscientific approaches, abundant research exists within the field of facial processing and decision-making, but this research has not been informed by intersectionality. Extant studies have investigated the neural correlates of "social categories" (Wiese et al., 2008; George, 2016; Stolier and Freeman, 2017; Delplanque et al., 2019; Brooks et al., 2020), using narrow examinations of single constructs such as sex/gender, racial categorization, race-related prejudice or sex/gender stereotyping (e.g., Kaul et al., 2011; Senholzi et al., 2015; Mattan et al., 2018; Fisher et al., 2020). To our knowledge, only one study has investigated the neural correlates of face processing of multiple social group memberships in face processing.

In their paper "Neural pattern similarity reveals the inherent intersection of social categories," Stolier and Freeman (2016, p. 795) suggest that the social categories of sex/gender, race, and emotion expression are "inherently intertwined" in the neural process of facial recognition. Their behavioral and fMRI experiments employing representational similarity analysis demonstrate that both the subjective perception and neural representation of social categories is contingent on participants' social-conceptual knowledge of identity-related stereotypes. For instance, in emotional categorization, Black faces were disproportionately categorized as angry, while female faces were disproportionately categorized as happy. The subjective interdependency of social categories in face processing was also represented in differential brain activity within the orbitofrontal cortex and right fusiform cortex. Interestingly, visual similarities of image silhouettes or pixel-intensity did not fully explain the intertwined aspects of the social categories at the neural level, reinforcing the interpretation that it is the subjective, social-conceptual knowledge that underlies the brain's processing of these identity categories. Findings from this study show that

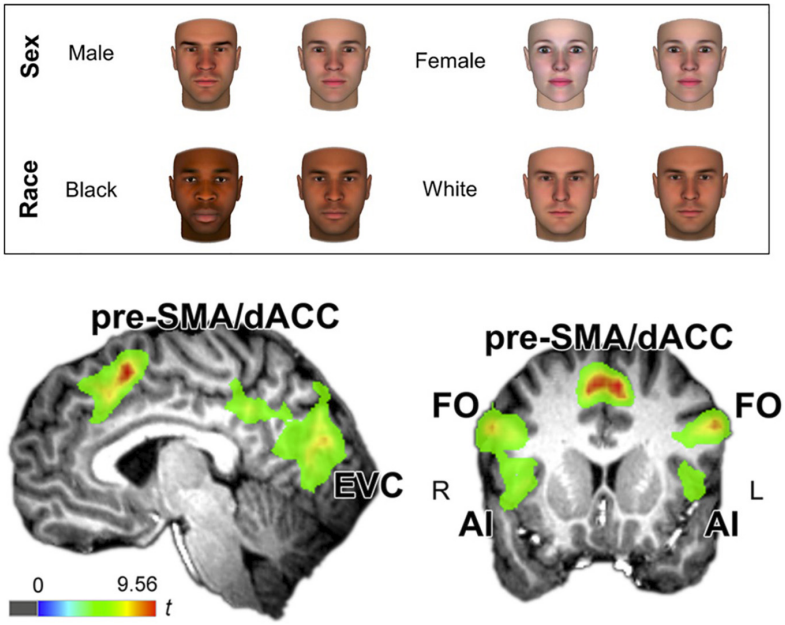

FIGURE 1 | From Stolier and Freeman (2017) (CC-BY). Above: This example shows the use of stimuli in Cognitive Neuroscience. It demonstrates the challenge when attempting to visualize categories of social identity and it also demonstrates how these attempts reify structural power because, as shown, here, the category of "Black woman" misses it again to be shown. Below: The brain images show the neurobiological correlates of "atypicality". Participants were presented with faces that had to be categorized corresponding to their "gender and racial typicality". Activation was found in the cingulo-opercular network consisting of presupplementary motor area and dorsal anterior cingulate cortex (pre-SMA/dACC) and, centrally, the anterior insula/ and the frontal operculum (AI/FO). This pattern of activation suggests the engagement of conflict monitoring when atypical faces are shown. R: right, L: left. EVC: early visual cortex, specific brain activation discussed elsewhere in the cited paper showing the processing of target categories presented in the study.

people's social stereotypes about particular intersected identity categories are reflected in both subjective judgments and neural representation in a clearly interdependent manner, revealing a possible effect of social inequality in the neurobiology of face perception.

This study by Stolier and Freeman (2016), demonstrates both the strengths and weaknesses of this type of "intersectional" research. One strength is that, despite the study's focus on the brain "basis" of intersecting social categories, the authors' conclusion that subjective social stereotypes shape the neural processing of faces elevates a social interpretation of face processing over a purely biological interpretation, and thereby avoids the pitfalls of resorting to biological essentialism. The authors also recognized as a main limitation that their findings "are mute with respect to the origins of the stereotypical associations studied here" and suggest that these could result from cultural transmission and implicit learning (Stolier and Freeman, 2016, p. 797). They do not interrogate this finding any further; in this regard, they sidestep the question of whether these subjective stereotypes are "fixed" at the level of the brain or whether they can be changed, and instead suggest that future studies should aim to manipulate participant's social stereotype in order to improve causal inference. Further, they do not discuss how socio-structural power dynamics may influence the development of stereotypical social categorization, thereby treating each of the categories as "neutral." As a result, even when adopting an explicit focus on the contributions of subjective social-conceptual knowledge to processing of social categories, research that aims to localize distinct patterns of neural activity related to intersectional categories in the brain runs the risk of inadvertently biologically essentializing these categories, simply in a more multifaceted, "intersectional" manner than arises from the "traditionally" separated social categories. This significant stumbling block may be one reason that neurofeminists have skirted the issue of intersectionality to date (Fitsch et al., 2020). Despite these limitations, Stolier and Freeman's work is nonetheless a contribution to the neurofeminist field as it provides support for the constitutive role of social experiences, in particular intersecting social group membership, in the subjective perception and neural processing of faces, and highlights that processing of intersectionality is not purely stimulus-driven.

Will engaging in this type of research be a fruitful avenue for neurofeminism? To counteract the limitations of this type of research, consideration for the interdependence of intersected identity categories needs to be contextualized within an understanding of socio-structural power dynamics. This includes an understanding of the relation between social group memberships and corresponding power differentials between researchers and participants. The social categories of sex/gender, race, and emotion are not neutral, independent categories within or across social group membership. Adopting an approach like that of Chaney et al. (2020), where the processing of social group membership is considered together with who is processing these social cues, will further expand our understanding of

the context-contingency of processing group memberships. Finally, developing studies that not only manipulate social group stereotypes, as suggested by Stolier and Freeman, but also manipulate the social power dynamics, could provide new insight into the brain processing of sex/gender.

In this section, we highlight how the use of intersectionality in research that aims to understand the psychological and neurocognitive processing of social group memberships could lead to new research avenues in the neuroscience of sex/gender. However, the ways in which intersectionality is incorporated into this research is not without an important consideration of shortcomings. Given the difficulties that arise when trying to reconcile an inherently reductive, quantitative approach to producing generalizable knowledge about the brain (i.e., the approach that forms the foundation of the scientific method), it is unclear if critical neurofeminism can engage with this type of research without risking harm related to biological essentialization of "intersected" categories. In the following section we consider whether psychology or neuroscience can accommodate an intersectionality perspective at the epistemological level without inadvertently expanding notions of biological essentialism through harmful dimension reduction of social categories in the brain.

RESEARCH THEME #3: HOW EPISTEMOLOGY CAN BENEFIT FROM INTERSECTIONALITY

A third type of research uses intersectionality to interrogate epistemologies in psychology. Instead of informing the selection of the research population (theme 1) or informing both the research questions and methodical considerations such as choice of stimuli (themes 1 and 2) and interpretation of findings (theme 1), here intersectionality is used to critically interrogate the foundations of knowledge production in psychology. By considering knowledge as political, embedded in power dynamics, and bound to human experiences, the intersectionality perspective on knowledge production is viewed as a critical process of continuous transformation (Marecek, 2016; Else-Quest and Hyde, 2016a,b; Grzanka, 2018; Collins, 2019; Rice et al., 2019). In line with previous work by feminist science and technology scholars and philosophers (Haraway, 1984; Longino, 1987; Fausto-Sterling, 2000; Schiebinger, 2001; Harding, 2006; Hammonds and Herzig, 2008; Subramaniam, 2009). This position on defining "knowledge" renders the knower's social position a constitutive part of knowing, where knowing is an ever-changing process (Anderson, 2020). Because one's social position constitutes a central element of what knowledge is, this position also informs how empirical inquiry can be or should be conducted within a particular knowledge domain. This idea stands in stark contrast to the positivist epistemologies that dominate much of psychological science, wherein observable evidence is the only form of defensible scientific findings, and only "facts" derived from the scientific method can support legitimate knowledge claims. Intersectionality research of this third type disrupts this assumption and related practices, and in doing so generates novel avenues for psychology (Warner et al., 2016).

In a recent publication, Settles et al. (2020) highlight epistemological points of rupture between an intersectional and psychological perspective on knowledge production. Conceptually, these ruptures are reflected in how intersectionality considers "generalizable" explanations of psychological knowledge to be probable *distortions* of the investigated phenomenon. Methodologically, intersectionality challenges the notion of psychological norms and their associated measurements in favor of modes of inquiry oriented toward diverse participants' lived and historical experiences, especially when engaging in quantitative research (Bowleg and Bauer, 2016). Further, conceptual and methodological shifts are currently being observed in the involvement of the participant as co-creator of the research. Overstreet et al. (2020) suggest that research informed by intersectionality demands participant involvement in the development of the research question and methods, while also requiring the researcher to reflect on how systems of power may bias the assumptions and practice of psychological research. An intersectional perspective necessitates that psychological knowledge, theory, and research must be oriented toward social justice actions and goals, making social activism a central consequence of advancing psychological knowledge (Settles et al., 2020). To do so requires an interdisciplinary approach in order to adequately socio-historically situate the participants, the phenomenon, and the knowers. This approach to producing knowledge goes against the traditional structure of academia and psychology (Warner et al., 2016) and questions numerous foundational research practices in psychology.

Despite its rich conceptual and methodological ramifications, work that uses intersectionality to critically analyze psychological knowledge production tends to be devalued and is predominately absent from mainstream psychological literature. Settles et al. report that critical intersectionality research in psychology is subject to epistemic exclusion, wherein the research itself is marginalized and undervalued as contributing minimally to the advancement of psychological knowledge. This exclusionary practice translates to a general lack of interest, or else a perception that this work is inaccessible, which results in various bias-inducing practices such as the marginalization of intersectional work within specialized journals (Settles et al., 2020). This publication bias in turn leads to an epistemic bias in mainstream psychology, which results in the disproportionate propagation of less critically conducted, flattened intersectionality research of the sort commonly observed in the field of psychology (Bilge, 2013; Warner et al., 2016). Crucially, this form of epistemological exclusion also leads to even further biases in the broader culture of academia regarding both the value of this critical work and the recognition of those conducting it—scholars who often themselves occupy marginalized positions. Settles et al. (2020) state: "Our position as marginalized scholars due to our identities (gender, race, and sexual orientation) is what brings us to the work that we do, including the populations we study, the questions we ask, and the theoretical lens we use." The challenges we face in the academy provide us with an insider perspective

on the epistemic exclusion of intersectionality in psychology and the implications such exclusion has on academic careers, including our own. In relation to this exclusion, Cole also raises concerns that the burgeoning use of intersectionality in research contexts is increasingly disconnected from the lives and concerns of women of color, as are the contributions of Black women scholars (Cole, 2020). Committing to critical intersectionality research in psychology means risking that both your work and status as a scholar will be subject to exclusion and erasure, a position disproportionately experienced by minority scholars, who often face pressures to "mainstreamify" their research.

Although neurofeminists are committed to challenging and disrupting dominant positivist neuroscientific epistemologies (Bluhm et al., 2012), the use of intersectionality as a guide to reform neuroscientific knowledge production has not been observed until recently. In a publication entitled "Toward a Compassionate Intersectional Neuroscience: Increasing Diversity and Equity in Contemplative Neuroscience," Weng et al. (2020) propose that the practice of intersectional neuroscience should favor analytical approaches to understanding the brain that "accommodate neural diversity" in accordance with the notion that individual biologies are the product of highly contextualized experiences. To preserve the brain's individuality but still allow for comparison between subjects, the authors recommend using multi-voxel pattern analysis (MVPA), a multivariate method that uses machine learning to derive brain activity patterns predictive of mental states (Weng et al., 2020). Because this method does not require normalization of brain data and focuses on changes in patterns of brain activity within an individual, the authors argue that MVPA better accommodates the inclusion of "non-normal" brains (Weng et al., 2020). That said, though it avoids normalization of brain activity by focusing on within-subject pattern similarity, MVPA is not "intersectional" *per se* as this approach can be used without any consideration of socio-structural power dynamics or social justice. Weng et al. also contend that intersectional neuroscience should be concerned with conducting research that includes hidden, underrepresented, and marginalized populations and involve a process of "partnering" with participants rather than generating information "about" them. Community-based participatory research reduces power imbalances and generates projects that are rooted in prosocial behavior and empowerment. In combination with the suggestion to use MVPA, a research program co-created with intersecting marginalized populations shifts the focus from the neuroscience of differences to a neuroscience of inclusivity and similarity, both central principles of intersectional research. These approaches to conducting neuroscience facilitate engagement with participants in a way that provides social context to the kinds of generalizations that can be meaningfully drawn from brain data without resorting to harmful reductionism, thereby avoiding or minimizing the kind of distorted "generalization" that arises from ignoring intersectionality. Future work in neurofeminism could benefit from these suggestions for the conduct of intersectional neuroscience.

Neurofeminists have also proposed epistemological frameworks where the relations between knowers and socio-historical contextualization of the phenomenon are constitutive of neuroscientific knowledge. Roy (2018) proposes a multilevel framework of knowledge production, promoting transformative approaches of conducting research that are rooted in feminist theory and activism. Roy envisioned the capacity of researchers to produce socio-historically informed scientific knowledge, even while working within technoscientific and reductionist environments, through a process of knowledge reappropriation and meaning attribution. In her project "The Co-Production of Knowledge by Reproductive Justice Advocates and Molecular Biologists," Roy used this approach to interrogate women's reproductive health inequities in light of the NIH policy requiring sex-balanced research[3]. In bringing together neuroendocrinologists and reproductive rights activists, this project highlighted differences in understanding of women's reproductive health and related policies across knowledge-holders, and demonstrated how creating space for those conversations to take place can generate novel ways for feminists to engage with neuroscience.

Similarly, neurofeminist Gillian Einstein has developed a "situated" approach to neuroscience which parallels the epistemological vision common to this theme of intersectionality research. Einstein (2012) proposed an epistemology which holds that knowledge about the nervous system is "situated" within the multiple hierarchical and socially constructed interactions that involve participants' experiences, experimenter's positionality, and technological constraints (Einstein, 2012). This "situated" practice of neuroscience demands that intersecting social identities inform and are informed by varying biologies (Einstein, 2012). Einstein's "very mixed methods" approach combining qualitative, quantitative behavioral, and quantitative neurophysiological methodologies, was recently used to investigate the multidimensionality of pain experiences in Somali-Canadian women with female genital cutting (Perovic et al., 2021). Importantly, an advisory group from within the participant/target community was created to inform every step of the study development. By combining in-depth interviews about women's experiences of pain, standardized pain questionnaires, and the physiological assessment of pain in the vulvar region, Perovic et al. (2021) were able to produce novel neuroscientific knowledge about unique pain experiences that intersected with women's experiences of immigration and cultural acceptance, and in doing so brought to light important considerations for clinical and health advocacy, thus directly contributing to social justice.

From this brief analysis, we highlight the emergence of novel investigative approaches grounded in intersectionality as way of exploring alternative models of knowledge production that are centered around interdisciplinarity, avoiding undue generalization, minimizing the power imbalance between participant and experimenter, and co-creating research for and with hidden populations. These approaches, in addition to extant feminist epistemic alternatives to scientific knowledge production (e.g. Hammonds and Subramaniam, 2003; Richardson, 2013; Roy, 2018; Jordan-Young and Karkazis, 2019),

[3]http://wgss.emory.edu/RoyLab/

approaches grounded in participatory designs (e.g. Buchmüller et al., 2011) and epistemic injustice (Fricker, 2007; Donnelly, 2018), challenge the very foundations of the dominant mode of knowledge production in quantitative fields and constitute a rich theoretical and methodological foundation for an intersectional neuroscience of sex/gender.

ADVANCING NEUROFEMINIST RESEARCH WITH INTERSECTIONALITY

Intersectionality is undoubtedly a fertile feminist theoretical framework for many disciplines including neuroscience, particularly as scientific narratives around women's brains and the brains of sex/gender-non-conforming people tend to be essentialized and decontextualized (Fine, 2010; Bluhm et al., 2012; Dussauge, 2014; Joel and Vikhanski, 2019; Jordan-Young and Karkazis, 2019; Rippon, 2019; Llaveria Caselles, 2021). In focusing on three themes of psychological research informed by intersectionality, this analysis identifies specific areas, practices, and critical positions that have the potential to advance the feminist practice of neuroscience.

With regard to theme one, which described intersectionality-informed research on health inequality, we identify the following main areas for advancement: First, neurofeminism will benefit from shifting focus to engage in neuroscientific research that is *systems-centered,* wherein oppressive social structures impacting inequalities in sex/gender-related brain health are modeled and tested. The operationalization and integration of social-structural variables in understanding sex/gender differences in brain health leaves less room for reductive, essentialist explanations that risk inadvertently reinforcing oppressive structures. This approach may also facilitate the connection between our understanding of brain health equality and the need for social change. Incorporating policies and practices, occupations, laws, familial organization, migration status, racial minority status, economic characteristics, etc. into neuroscientific research designs not merely as demographic variables of description but as intersected categories of study will make it possible to empirically demonstrate impacts of social inequality within neuroscience. Police arrests, incarceration history, access to social security, and neighborhood characteristics are a few examples of variables that could be included in order to model and test effects of social structures on health or other outcomes. A second area of advancement is to begin adopting research designs that explicitly contrast privileged and targeted groups assessed before and after the implementation of certain policies, services, or appearance/disappearance of organizations (for more insights on research designs centered on social structure see Krieger, 2019), as high-quality longitudinal analysis can be a big step forward in understanding the impact of socio-structural factors on health inequality. Finally, as the availability of a large brain datasets with greater socio-structural resolution increases, socio-structural causal models will become feasible – although, of course, big data analysis should not be regarded as the final approach to capture intersectionality and diversity since sex/gender and race biases harbor their own risks (Fitsch et al., 2021). Focus should be placed on hidden/invisible populations, and on elucidating how intersecting social group memberships can push individuals into vulnerable positions (del Río-González et al., 2021). Some of this work has already been initiated by neurofeminist scholars (e.g., Somalian immigrant women in Canada with FGC; Perovic et al., 2021), but this work needs to be further expanded.

Against the backdrop of theme two, which discussed research that aims to understand the psychological processing of intersecting group memberships, we identified the following main areas for advancement: First, neurofeminist researchers should place focus on understanding the nuanced interdependence of intersecting identity categories and how these categories can or should be operationally defined. Neurofeminism's current consideration of sex/gender is explicit, rationalized, and extensively grounded both conceptually and empirically. Conversely, the neurofeminist analysis of sex/gender as interdependent with other social categories such as race is at present often submerged – and concerning face recognition research even being taboo (Kuria, 2014; Kaiser Trujillo et al., forthcoming). In order to avoid treating social categories as homogenous and fixed, neurofeminist research must be dedicated to interrogating and challenging the operationalization of such categories (Marecek, 2016). Second, consideration for the socio-structural interdependence of social categories must be contextualized within systems of privilege and oppression. For instance, developing studies that manipulate power dynamics related to group memberships could provide new insight into the brain processing of sex/gender. As well, adopting an approach like that of Chaney et al. (2020), where the processing of social group membership is considered together with *who* is processing these social cues, can open new avenues for a socio-historically situated sex/gender neuroscience.

Finally, the third theme of research elucidates a more fundamental potential division between intersectional and conventional neuroscience perspectives, particularly in regard to the roles of experimenter and participant, and their involvement (or lack thereof) in the production of knowledge. Considering how to reconcile epistemological disagreements between these two frameworks highlights a clear and pressing need for an expansion of interdisciplinary approaches to neuroscience research that employ mixed methods, consider principles of inclusivity and diversity in morphometrical neuroscientific measures over "normalization," and demand reflection on the socio-historical situatedness of not only the participants but also the researchers and the research itself. To date, epistemological propositions made by neurofeminists such as Roy (2018) and Einstein (2012) align well with an intersectional perspective and can also generate novel neurofeminist investigative avenues, but more research using these perspectives remains to be done. Additionally, as the neurofeminist field grows it will be crucial to expand means of enhancing awareness around the importance of recognition and inclusion of this type of research and the scholars conducting it in mainstream literatures. Initiatives such as the Neurogenderings Network[4] have been developed in response to epistemological exclusionary practices, and can be instrumental

[4]https://neurogenderings.wordpress.com/

in preventing epistemic oppression and erasure. Together, these avenues of promoting an awareness as to the situated nature of scientific knowledge and the plurality of knowledge holders open up numerous avenues of future direction for the field of neuroscience.

LIMITATIONS

While our analysis allowed us to identify where intersectionality can advance neurofeminist research, it is also subject to several limitations. First, our categorization of intersectionality research within the three themes identified was conducted to facilitate the present analysis and should therefore itself be considered as contextually situated within a discussion of neurofeminism rather than as an absolute or exhaustive taxonomy of intersectionality research. Second, situating our analysis using psychology as a background framework, we certainly narrow the interdisciplinary focus that neurofeminism champions. Neurofeminism is informed by several disciplines, some of which themselves already conduct epistemic, ethical, and critical race analyses. Thus, future research must work to further unearth the specific epistemic differences and overlap between interdisciplinary approaches to knowledge production in psychology and elsewhere. For instance, the body of clinical and biomedical research grounded in intersectionality is growing, and may certainly provide insights for neuroscience (Hankivsky et al., 2017). Clearly, intersectionality's explicit focus on social change will be of benefit for neurofeminism through widening the sex/gender-centered scope of this community. We are aware that for some scholars, aspects of the research themes we highlight here may not be considered truly intersectional research. Similarly, when discussing neurofeminism and its position with respect to intersectionality, we purposely aim to reflect more broadly on the research, but recognize that in this approach may have overlooked some relevant neurofeminist and intersectional research.

CONCLUSION

Intersectionality can contribute to advancing neurofeminist research and practices in the study of sex/gender. Due to its capacity to expand our understanding of sex/gender into a broader landscape of social categories, incorporating approaches from intersectionality can inform the study of these categories while promoting research that measures or otherwise accounts for their interdependency rather than falsely orthogonalizing them. Further, intersectionality's focus on social justice, discrimination, and equality resonates with the core fundaments of neurofeminism. However, neurofeminism, a field operating within the neurosciences, is closely bound to the scientific method, and as such any neurofeminist research incorporating intersectionality must critically consider its own methodological and socio-historical situatedness in order to minimize the risks of biologizing and essentializing intersected identity categories and thereby undercutting the social-justice-oriented goals of the endeavor.

AUTHOR CONTRIBUTIONS

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

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