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COMMENTARY

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Confronting ethical and social issues related to the genetics of musicality

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Abstract

New interdisciplinary research into genetic influences on musicality raises a number of ethical and social issues for future avenues of research and public engagement. The historical intersection of music cognition and eugenics heightens the need to vigilantly weigh the potential risks and benefits of these studies and the use of their outcomes. Here, we bring together diverse disciplinary expertise (complex trait genetics, music cognition, musicology, bioethics, developmental psychology, and neuroscience) to interpret and guide the ethical use of findings from recent and future studies. We discuss a framework for incorporating principles of ethically and socially responsible conduct of musicality genetics research into each stage of the research lifecycle: study design, study implementation, potential applications, and communication.

KEYWORDS

bioethics, education, genomic, music cognition, rhythm

PRELUDE

Music plays a profound social function for humans. Whether in times of joy or struggle, there is mounting evidence of its potential to impact well-being.[1,2] Musical engagement during the Covid-19 pandemic is a prime example of the impact of music on well-being.[3,4] Scholars have proposed that human musical traits evolved to support social engagement, group cohesion, communication, parent–child wellness, and other positive societal outcomes.[1,5]

SETTING THE STAGE: THE EMERGENCE OF MUSICALITY GENOMICS AS A SUBFIELD

Musicality can be broadly defined as the capacity to perceive, appreciate, and create music;[6] in other words, the full spectrum of ways in which we as humans interact with music. Given that musicality is a ubiquitous feature of all known human cultures[7] and that human sensitivity to music seems to emerge early and spontaneously, many authors have proposed the existence of specific biological forces that push humans to create and engage with music;[8] some of these forces also exist in other animals, such as primates and songbirds.[9,10] It is worth pointing out that music can be defined very broadly, that is, encompassing "a variety of concepts surrounding human activities that may include structured sound (…[i.e.] pitch height, pitch duration, timbre, and form), communicative meaning, rituals, and constitutive body movements (singing, playing an instrument, gesturing, clapping, dancing)."[11]

Research into the biological basis of musicality has proceeded on multiple fronts in parallel:[9] psychology, neuroscientific, medical, genetic, cross-cultural, and cross-species. Three decades of neuroscience research have revealed critical brain pathways that enable the perception and production of music, including neural substrates of music training–dependent plasticity[12] and, similarly, many other correlates of musical skill.[13] Musicality plays an important role in healthy child development,[14] and, furthermore, trained musicians appear to experience a constellation of health benefits along with some particular health risks.[15] These intricacies of the biology of musicality and its relationship to biomedical conditions[16] strongly suggest that *musicality is a health trait*, and that *population health* approaches can foster a scientific understanding of musicality.

Insight into the potential biological origins of musical behaviors—and the underlying neural basis—comes from twin- and other family-based evidence of the heritability of varied musical traits (i.e., heritability estimates demonstrate that a proportion of phenotypic variance is accounted for by genetic influences), including music aptitude,[17] musical practice,[18] and music achievement.[19] These studies converge in pointing to moderate genetic influences on musicality. Additional clues about the molecular genetic substrates came from genomic linkage studies of musical traits,[20] though there are some methodological limitations to this approach.[21] With the rise of scalable musicality phenotyping and the advent of high-throughput genome-wide genotyping, Gingras et al.[22] called in 2015 for large-scale, appropriately powered genome-wide association studies on carefully selected musicality traits that are deemed to be relevant within a given culture[11] and can be used consistently across many cultures. The current paper continues the discourse about the emergence of this subfield with a focus on the ethics-legal-social-implications (ELSI) of musicality genetics.

These ELSI discussions are particularly timely in relation to the recent publication of the first large-scale genome-wide association study (GWAS) of a musicality trait.[23] This recent GWAS of beat synchronization reveals the genetic architecture of the human tendency to move in time with a musical beat (or pulse), a behavior ubiquitous in human cultures.[7] The preceding two decades of research have shown that beat perception and synchronization emerge from tightly coupled coordination between auditory and motor areas of the brain,[24] such that in music we hear a regular pulse to which we can synchronize.[25] Complementary neurobiological and psychological evidence previously highlighted how beat synchronization is integral to music-making, dancing, and singing. Rhythm, and in particular synchronization to the beat, is situated within the landscape of musicality as a platform for exploring fundamental mechanisms of sensation,[26] prediction,[27] coordination,[24] and reward.[28] Accordingly, an additional study[29] utilized a combination of genomic and family-based methods to demonstrate that the genetic architecture of beat synchronization is associated with individual differences in many different aspects of musicality (including music aptitude, musical practice, and musical flow proneness) and to test competing hypotheses about how the environment mediates and moderates genetic differences between individuals (including via gene–environment correlations, i.e., the idea that genetic variation may influence different individuals to seek out different environments).

SITUATING THE BEAT SYNCHRONIZATION GWAS: RELEVANCE FOR BASIC SCIENCE AND CLINICAL-TRANSLATIONAL EFFORTS

The beat synchronization GWAS[23] highlighted the polygenicity of the trait and opened new avenues of scientific inquiry at the interface of musicality, cognition, human genetics, and neuroscience. This study was initially motivated by the hypothesis that knowledge of biological mechanisms underlying musical rhythm will open a window into cascades of biological processes that ultimately affect the neural substrates of rhythmic behavior. This line of inquiry may eventually contribute to clinical-translational applications of beat synchronization including, among others, early detection of childhood speech-language-reading disorders (which are linked to atypical beat synchronization[30]) and personalizing music-based treatments[16] (e.g., for Parkinson's and other motor disorders[31–33]). During the study, it also became clear that biomechanical rhythms (e.g., circadian, breathing, etc.) may share genetic factors with the human capacity for musical rhythm. These findings motivate further research aimed at understanding the complex interplay between the rhythms of body and mind in the context of musicality. However, the opportunity for this line of inquiry to deepen our appreciation of our shared human experience is as great as the potential for misuse of such research. Moving forward thus requires responsible sensitivity to the ethical questions that accompany the emerging field of musicality genetics.

INDIVIDUAL DIFFERENCES APPROACHES: CURRENT UTILITY JUXTAPOSED WITH PROBLEMATIC HISTORY

When a feature of human individuals and societies, such as musicality, is omnipresent and simultaneously interacts with culture, the biological contributions can be difficult to study. Even small interindividual differences in rhythm/beat synchronization behaviors provide a tractable mechanism for tapping into the biological processes underlying the shared human experience of music, because these phenotypic variations can be studied in relation to genetic variations in a population (as in GWAS methods). On one hand, the measurements themselves are only representations of natural human variation. Yet, *individual differences approaches* cannot be context-free; human decisions always go into defining what a trait is, how it is categorized, and how it is valued. This fact is especially relevant to our ELSI discussions, given that the decisions that people made in the last century about how to define and measure constructs such as intelligence still affect cognitive science and complex traits research today. This history creates a delicate set of circumstances, because 20th-century eugenicists were specifically focused on channeling racism into social and reproductive policies.[34] In particular, the advent and fine-tuning of IQ tests was expressly to support white supremacy and its hereditary theories of social hierarchy;[35] such research was later used to defend forced sterilization, restrict immigration, and support other corrupt social policies.[36]

One of the founders of the music cognition field (Carl Seashore) was a declared eugenicist whose influential music aptitude tests were at least partially intended to uphold (false) theories about differences in musical aptitude across people assigned to different racial groups.[37] Thus, even though now we may take the position that part of our job as biologists studying musicality, the brain, and cognition is to quantify and describe individual differences—toward what we tend to see as an ethically and socially responsible set of basic science and translational motivations—the quantification must be done in a certain way to prevent the nefarious usage and misappropriation of frameworks and research findings.[38] To this point, safeguards are needed at each stage of the research lifecycle; we will return to these ELSI principles and how to apply them to musicality genetics research in the latter part of the article.

SOCIALLY VALUED TRAITS, ABILITY RANKING, AND INCORPORATING NUANCED UNDERSTANDING OF THE HISTORICAL CONTEXT INTO OUR PRESENT-DAY STUDIES

We must keep in mind that individual differences in beat synchronization (or any other musical trait, such as rhythm perception, memory for musical sequences, and pitch perception) can also be perceived in a sociocultural context in which some members of a social group are judged to have "good" musical skills and others to have "bad" musical skills. Here, we should clarify the distinction between characterizing *variation in a measured ability* and *placing value judgments on ability*. We believe that musicality genetics research that uses dichotomous or continuous metrics of musicality traits should be solely geared toward characterizing variation underlying measured abilities for useful scientific description (i.e., to study its biological processes, its cognitive mechanisms, or its associations with other health traits), and specifically not to promote the metric or the resulting measurements as a value-laden lens through which to view the trait. We also need to acknowledge that there may be tradeoffs between different abilities; for instance, increased accuracy and precision in rhythm could potentially covary with decreased freedom, expressivity, and creativity.[39] Keeping this complexity in mind could be a safeguard against allowing ableism to infiltrate into the research. Furthermore, since music is a sociocultural phenomenon and because music aptitude testing emerged from the eugenicist school of thought, scientific characterization of musicality traits (and particularly music aptitude) cannot be context-free. To this point, there is recent evidence that individuals' perceived musicality affects others' moral considerations of them.[40] All together, this conundrum is similar to the challenge of quantifying IQ even for basic science purposes, given the eugenics history and context of studying individual differences in IQ.[35,41]

Taken together, the study of a trait that lends itself to this type of "ability ranking" comes with (1) a grave responsibility for the nuanced and ethical use of particular statistical models that cast individual differences along a continuum; and (2) socially responsible research communication that considers the context in which research findings may be received and used by researchers, the media, and the general public. Where culture, environment, and biology interact in such profound ways, it is especially crucial to understand what the results of genome-wide interrogations of musicality can—and cannot—tell scholars about the causal drivers of such extraordinarily complex behavior.

INTEGRATING ETHICAL AND SOCIAL PERSPECTIVES INTO THIS NASCENT FIELD

Therefore, in this paper, we wish to (1) highlight the methodological scope and limitations of GWASs and polygenic scores (PGSs); (2) bring attention to key ethical and social questions that accompany this nascent field of musicality genetics; (3) clarify how one should and should not interpret the findings of the GWAS of beat synchronization and results of other future GWASs of musicality traits; (4) draw attention to parallel challenges on diversity, equity, and inclusion in the music cognition and human genetics fields; and (5) outline principles of a framework that upholds ethical and socially responsible conduct of musicality genetics research including use of this new knowledge (Figure 1). In this article, we have come together as five of the authors from the beat synchronization GWAS, plus three additional authors who are scholars in the ethics of social/behavioral genomics, ethno/musicology, and developmental psychology, joining forces to actively embed musicality genetics into an ethical and socially responsible research lifecycle. We acknowledge that this ethical and social framework is simply a starting place for approaching an intricately complex set of issues and that there are limitations that may have been overlooked at the time of writing this piece. Nevertheless, we believe that there is significant value in commencing this discourse at the present time.

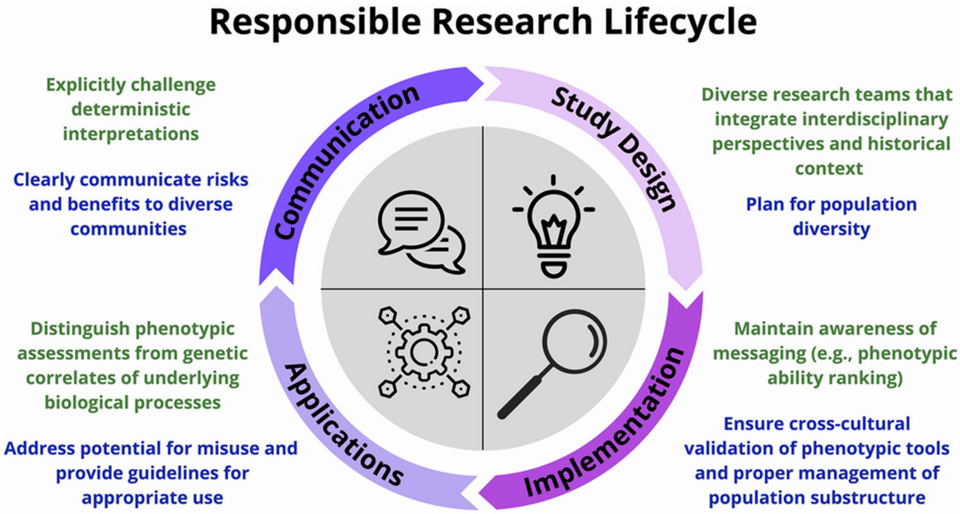

FIGURE 1 Schema for embedding socially and ethically responsible decision-making into the research lifecycle. Here, we conceptualize the incorporation of socially and ethically responsible decision-making into the four main stages of the research lifecycle (from top right, clockwise): study design, study implementation, potential applications, and communication. Text in green in each quadrant signifies steps that can be taken at each stage pertaining to one example of an ethical/social principle or goal in musicality genetics research: during *phenotyping*, the goal of avoiding ability ranking based on genetics. Potential steps toward another principle: *Inclusion of culturally and genetically diverse participants*, in each phase of the research cycle, are shown in blue text in each quadrant of the lifecycle.

Methodological scope and limitations of GWASs and PGSs

GWASs measure the correlation between frequencies of specific alleles (one of two or more alternative forms of genes or variants) and a particular measured phenotype. While it is tempting to attribute causality to GWAS results, it is important to acknowledge that a GWAS is fundamentally a correlational analysis and causation cannot be directly inferred. Specific confounds that could lead to an inference of causal influence of genes (as opposed to correlation with genetic variation) include but are not limited to: sociocultural confounds[42] (such as the cultural values that go into deciding what qualifies as an acceptable phenotype[43]), selection bias (i.e., ascertainment bias for research participation[44]), phenotypic hitchhiking (where a substantial subset of individuals classified as a particular phenotype are also more likely to present with a second phenotype that is correlated for non-genetic reasons, thus confounding the interpretation of GWAS results), or gene–environment correlations[45] (in which genetic influences are associated with particular environments). Additional confounds could include collider bias[46] (when exposure and outcome each influence a common third variable but that third variable has been controlled for in the analysis), as well as measurement error.

Careful selection and measurement of phenotypes can help rule out some of the more obvious confounds (i.e., self-confidence; see Niarchou et al.[23]) but cannot completely rule out many more nuanced biases. For instance, the GWAS of beat synchronization showed moderate heritability of 13–16%. While in line with other complex traits,[47] this estimate simply tells us approximately how much of the interindividual variation observed in the phenotype is associated with genetic variation *in a given population (US-based individuals with European ancestry in the 23andMe collection) at a given point in time (21st century)*. It would be possible to obtain different heritability estimates in another culture at another time[48] due to the possibility of culture supporting or preventing gene–environment correlations. Even so, a GWAS of beat synchronization does not quantify environmental influences on musicality, and it is quite clear from cross-cultural musicology findings[11] and work on the development of musical expertise[49] that musical environments modulate human musicality to a great extent.[50]

One tool that has been used widely to harness GWAS-derived information is the PGS. PGS reflects the cumulative contribution from thousands of genetic variants to a particular trait or condition; PGS analysis yields a per-individual score. PGS can be used to test a wide range of genetic hypotheses. In some clinical applications, PGSs are used to identify subgroups of people who, *on average*, may benefit from a particular clinical intervention.[51] In Refs. 23, 29, and 52, PGS analyses were used to test whether genetic variation correlated with beat synchronization in one sample was, en masse, also correlated with rates of musical engagement in an independent sample. In the experiment of Ref. 23, the PGSs were able to explain only 2% of the variation between musically active individuals and unscreened controls. This finding provided face validity for the results of the initial GWAS, but falls far short of any predictive model that could be used for an individual in a clinical setting.[53] It is important to note that phenotypically measured musical engagement and training variables account for much more phenotypic variability in musical ability than PGSs.[52]

Ethical and social questions in musicality genetics

For both ethical and methodological[54] reasons, PGSs cannot and should not be used to rank *individuals* or to make inferences about *individual* musical talent or aptitude. Such uses, in addition to the ethical problems they pose, are based on a distortion of these scores' predictive accuracy. Cross-talk between the fields of ethno/musicology, music cognition, and human genetics is seeding an urgently needed ethical and social agenda at the time when discussions of such work on social media[55] and in the press[56–58] (c.f. Ref. 59) simultaneously carry both the opportunity to engage scientifically with the broader public, along with the potential for inaccuracies or mischaracterizations to go viral, especially when genetic variation linked to phenotypic variation is mistakenly interpreted as unchangeable heredity (see Ref. 60 for common misconceptions about heritability).

As an emerging field, it is our responsibility to discourage and mitigate against unethical and socially irresponsible usages of our research. Beat synchronization, for instance, is a result of complex and heterogeneous combinations and interactions of genetic and environmental factors over the lifetime. *Such scores will never be able to establish or definitively predict an individual's ability to engage with music* because they cannot capture the complex interplay of all the factors that contribute to musicality. Future research on the neuroscientific and clinical-translational aspects of musicality may eventually benefit from examining people with differing clinical profiles (or subsets) that, *on average*, differ in their PGSs (e.g., researchers could test these hypotheses by stratifying subsets of participants by PGS as a clinical screening tool for developmental reading or language-related impairments,[30] or as a predictor of response to music-based rehabilitation strategies for stroke). However, at present, it is clear that a PGS *cannot* be used to predict or label an individual's musical ability. In summary, PGS may be a useful translational research tool in this arena to test hypotheses about the nature of associations between individual differences in musicality and health conditions,[61,62] with its maximal specificity to identify subsets of patients who may benefit from particular clinical interventions customized to them (e.g., Ref. 63), but PGS is *not* a tool that can make specific individual determinations.

As we cross new frontiers in genetics research on human musicality, the pitfalls of GWAS and PGS are important to acknowledge, and, alongside the specter of eugenics, they raise important ethical and social considerations. First, we must again remind the scientific community that the study of human genetics and individual differences has been historically intertwined with racism, classism, ableism, sexism, and eugenics.[35,41,48] Barely a century ago, tools such as music aptitude tests were used to promote a racist agenda against African-Americans.[37,64] These tasks were designed in a culturally biased manner and then used to perpetuate the false narrative that people of African ancestry somehow had musical abilities that were less sophisticated due to genetic differences. Those study design decisions are not disconnected from current work; Seashore's assessments and subsequent similar instruments[65] have been used to characterize musicality in a very significant portion of individual differences studies of musicality, even now in the first two decades of the 21st century. Moreover, literature that has become a staple of the emerging musicality genetics subfield, that is, the first genome-wide linkage study of musical ability,[66] utilized Seashore's pitch and duration perception tasks as their primary phenotypes of interest. Yet, in those studies and related review papers,[67] the eugenics historical context is not mentioned or referred to in the slightest.

Moving forward, we believe that such omissions ultimately undermine the responsible and ethical research lifecycle, and ongoing field-wide efforts should promote awareness of the historical context (e.g., Ethics Working Group of the newly formed Musicality Genomics Consortium; https://www.mcg.uva.nl/musicgens2022/mission.html). Similarly to intelligence research barely a century ago, in which IQ tests were specifically used to perpetuate a racist agenda against people of African ancestry,[35,68] we must recognize that early music cognition tests were used in the same vein. Early research on both constructs (cognition and musicality) was deployed to argue that disparities in education are solely attributable to genes and impermeable to social policy.[37,69] It thus follows that the contemporary phenotypic definitions and modes of assessing intelligence and music aptitude, respectively, are not value-neutral: these phenotypes come with baggage that necessitates active engagement during the research process in order to anticipate potential downstream social harms (weighed against potential benefits) that could result from research that utilizes these phenotypes. The social harms of this research are not merely theoretical: supremacists are actively misappropriating research (e.g., the Buffalo shooter in 2022[38] or dangerous misuses of artificial intelligence facial recognition technology[70]), consistent with a long history of white supremacists co-opting information that researchers might otherwise think of as harmless.

We are thus here to open a dialogue about what can be done upstream in the research process to mitigate potential downstream harms, that is, misappropriation of research findings, and to instead conduct research on musicality genetics in a manner that boosts the possibility of benefits downstream.

Genetic essentialism and inappropriate uses of the PGS: How one should and should not interpret musicality GWAS results

The concept of genetic essentialism is defined as the temptation or tendency to oversimplify genetic causes of observable phenotypes.[71,72] Genetic essentialism is a useful concept for understanding one of several barriers in the public's understanding of the biology of complex (non-Mendelian) traits. It reveals how misunderstandings about the relationship between genotypes and phenotypes can lead to the potential misappropriation of research findings. Given the recent historical context and the continuing tendency toward genetic essentialism of complex traits, many ethical and social implications are imminent. In the near future, the direct-to-consumer genetic testing market may begin to offer publicly available genetic tests for "musical ability." Additionally, these scores could be used for eugenic purposes (e.g., as part of prenatal testing). Some *in vitro* fertilization clinics already offer polygenic embryo screening (PES[73]), that is, screening embryos for genetic risk of complex diseases, including psychiatric disorders, based on polygenic risk scores,[74] and might someday incorporate PGS for musicality into their services. There is no demonstrated clinical utility to PES for musical traits or most polygenic traits for that matter;[75] for this reason, we believe it would be inappropriate and unethical to incorporate it into clinical practice. Moreover, technological developments amplify the possibility of discriminatory use of PGS,[75] especially if they are used inappropriately to predict an individual's musical ability, for example, as a data point in considering whether to offer someone a record contract, or for admissions consideration to schools of music. Importantly, the advent of PGS for beat synchronization opens the door to genetic discrimination in musical education settings which are not protected under the Genetic Non-discrimination Act of 2008.[76] We reject any research program that tries to use individual differences in this way, and instead welcome the diversity of musical traditions, competencies, and experiences that flows from the continued and continuing renunciation of research founded on eugenic and ethnocentric principles.

We thus disavow such applications, both now and in the future, for the following reasons. First, as described above, the PGS reported in Refs. 23, 29, and 52 (as well as any future improvements and PGS of other musicality traits) can only account for a small fraction of musicality that is perceived as socially useful, for which environment, love of music, and intensive training are self-evidently necessary, if not entirely sufficient. Second, scholars caution against the potentially negative psychosocial impacts of receiving a PGS related to ability,[77] which is a highly plastic trait. Furthermore, the nonsensical application of PGS to embryo selection raises questions about how parental expectations based on PES decisions will affect rearing, children's health, life-long trajectories, and sense of autonomy. Third, the majority of GWASs are conducted using samples from participants of northern European genetic ancestries living in high-income countries[78]—the GWAS of beat synchronization included. It is important to note that many ELSI issues encompassing genetic essentialism (e.g., deterministic interpretations of genetic studies, along with connections to racism and ableism) apply broadly to any genetic studies of musicality (including family-based methods), while some related ELSI issues (e.g., PES) apply more narrowly to molecular genetic/GWAS studies.

Parallel challenges in diversity, equity, and inclusion in the human genetics and music cognition fields

Moreover, both the field of human genetics and the field of music cognition are currently encountering similar challenges[41,79] related to the overrepresentation of European/Western participants and related ascertainment bias issues, lack of diversity in the workforce (chiefly underrepresentation of individuals from non-European genetic ancestry), harmonization across different datasets, and reproducibility of research findings. Although more nuanced and less biased assessments of musicality have now been developed and statistically validated in large samples in multiple world populations and are in common use,[80–83] the continued Eurocentric frame of most music cognition and music education research still results in musical competencies being narrowly defined and viewed through the lens of Western classical music, including constructs such as beat synchronization.

In future work, it is crucial to begin to incorporate cross-cultural ethno/musicology perspectives in order to arrive at a more inclusive understanding of all of the forms that musicality can take across cultures.[11] For example, research in music cognition has shown that West African musicians show higher synchronization precision,[84,85] higher ability to synchronize to fast tempi,[86] higher ability to produce complex rhythmic patterns,[87] and higher ability to recognize culturally specific rhythmic patterns[88] compared with Western musicians. Communicating scientific ideas and hypotheses related to diverse cultural perspectives in musicality genetics research in popular media, for example, regarding selective pressures on survival and the social benefits of using musical rhythm for communication[89] and well-being, can open dialogues between scientists and the public around representation, diversity, and ethnocentrism, while reinforcing the relevance of this research for diverse populations.

Compounding this issue of Eurocentricity, the GWAS on beat synchronization was conducted using samples from participants of primarily northern European genetic ancestry living in a high-income country, a common design problem in genetic studies.[90] The PGSs derived from these GWASs have the highest predictive power in the populations represented in the discovery GWAS, due to differing allele frequencies and linkage disequilibrium patterns across populations.[91] Though all genes actually carry out fundamentally similar functions in all humans, the allelic variation that tags each gene varies across ancestries. This biological fact complicates cross-ancestry analyses. As a result, even in appropriate research contexts, most currently available PGSs (including those derived from the beat synchronization GWAS) likely do not translate well to populations of diverse or non-European genetic ancestries. Alternative, more sophisticated analyses (e.g., Ref. 92) may eventually be utilized to evaluate the generalizability of genomic results discovered in one population to another.

Embedding ethically and socially responsible decision-making into each stage of the lifecycle of research

To counter the myriad of flawed premises and conclusions that could become associated with this research, we can adopt an ethically and socially responsible research agenda that encompasses priorities recently voiced,[11,79,93] including making careful choices in particular about ethical and social issues common to music cognition and genomic research on complex traits. These choices include not only what to study and how to study it, but also how to publish results and how to engage society.[94] Principles of ethically and socially responsible conduct of musicality genetics research can be incorporated into each stage of the research lifecycle (Figure 1). For example, the overarching principle of *avoiding ability ranking based on genetics* can be tackled during each stage, that is, within (1) *study design*, by integrating interdisciplinary perspectives and historical context; (2) *implementation*, by maintaining awareness of messaging regarding phenotypic ability measurements or rankings; (3) *potential applications*, by distinguishing phenotypic ability rankings from the genetic correlates of underlying biological processes; and (4) *communication*, by explicitly challenging deterministic interpretations of findings (e.g., when findings are communicated via social media and the popular press).

The principle of *inclusion of culturally and genetically diverse participants* can be incorporated within (1) *study design*, by planning for population diversity and forming a study team that is culturally diverse; (2) *implementation*, by ensuring both cross-cultural validation of phenotypic tools and proper management of population substructure in genetic data analysis; (3) *potential applications*, by addressing the potential for misuse and providing guidelines for appropriate use; and (4) *communication*, by clearly communicating differential risks and benefits of the research and its applications to a diverse set of communities. These safeguards during the public communication phase are especially important given that risks and benefits are not the same across populations due to both historical context and bias of initial study samples and caveats of generalizing findings across populations.

We envision that operationalizing such principles would lead to multiple initial recommendations. For instance, during the *study design* stage of planning new work, researchers need to understand the historical context of cognitive genomics and how it intersected with eugenics-motivated early music cognition studies. Researchers could demonstrate this knowledge by being explicit about the context in papers and grant proposals, citing work that has covered links between eugenics and music cognition (e.g., Refs. 37, 64, and 95), and covering this history when teaching introductory music cognition and music history coursework.

During the *implementation* stage, inclusive recruitment strategies and careful analytic management of population substructure can be used toward overcoming the overrepresentation of European/Western participants in these studies. At the *potential applications* stage, we want to be very clear that PGS and similar analyses applied to individual genetic data should not be used to make deterministic individual inferences or rankings. Among the deterministic and misinformed applications that should clearly be avoided include any PES for musicality traits; there is simply no theoretical, ethical, or clinical justification for using PES in this way.

Regarding other types of personalized health and clinical applications, the majority of this authorship team believes it is reasonable for clinical-translational research using knowledge from musicality GWASs to proceed cautiously, potentially looking at the health benefits of personalizing treatment programs. We also recommend that *communication* about musicality genetics research in scientific and public media forums explains carefully how genetic influences only account for some of the variability in musicality traits in the population. Researchers should work with their press offices to steer the narrative away from genetic essentialism and toward a more nuanced framework in which environmental influences and complex interplays between genetic and environmental influences also play a significant role. For instance, heeding calls to the complex trait genetics field to consider FAQs regarding new GWASs,[96] the authors of the beat synchronization GWAS have provided a general-audience friendly summary of the study at https://www.vumc.org/music-cognition-lab/FAQbeatGWAS, and are encouraging an open forum for discussion about the study's implications. While these FAQs are a starting place, it is important to note that genetic research on musicality cannot be socially neutral, because musical ability itself is a socially valued trait.[40] Instead, both basic and translational approaches must have safeguards built into the research cycle (Figure 1) to prevent downstream harms, and research must be purposefully oriented toward the broad goals of improving human well-being, regardless of whether it is overtly framed as applied research.[2]

CODA: ORIENTING BASIC SCIENCE MUSICALITY RESEARCH TO THE SOCIAL FUNCTION OF MUSIC IN SOCIETY

To this point, the *social* function of music, coupled with how music-related activities may have provoked evolutionary adaptations,[8] highlights the basic science relevance of musicality genetics. As Lee[97] puts it, "we simply do not understand ourselves or the world well enough to predict everything we need or might need; basic scientific research ensures we are equipped to deal with issues beyond the limits of our present-day imagination, should they arise." Just as it is not possible to anticipate all the potential harms of research, society might ultimately benefit from unraveling phenomena, such as the role of biology in moving in synchrony to music, in ways that have not yet been imagined. Furthermore, the human capacity for musicality is not only about ability—it is very often broadly participatory[1] and has tremendous potential to bring people together,[2] impacting well-being and communication over the lifespan[61] via mechanisms still to be discovered. Individual differences in metrics of musicality traits, when used as the phenotypes for a GWAS, are generally a tool that can help us tap into biology, to help explain phenomena that humans largely have *in common*. Last but not least, musicality continues to be an excellent model to study basic neural mechanisms of mental prediction, motor coordination, and reward in the context of the full spectrum of human musical experiences, with the emerging possibility of bridging the gaps between genetic influences, culture, environment, and the brain.

AUTHOR CONTRIBUTIONS

Conceptualization: LKD, MDM, and RLG. Development of framework: LKD, RLG, and DOM. Writing initial draft: RLG, MN, LK, DOM, EB, and NJ. Revising and editing: RLG, SN, MN, DOM, MDM, EB, NJ, and LKD.

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COMPETING INTERESTS

All authors declare no competing interests.

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