INSTITUTO
UNIVERSITÁRIO
DE LISBOA

Correlates of music training: Plasticity or predispositions?

Ana Isabel Costa Correia

PhD in Psychology

Supervisors:

Professor César F. Lima
Associate Professor (with Habilitation), Iscte – University Institute of Lisbon

Professor E. Glenn Schellenberg
Professor Emeritus, University of Toronto Mississauga
Principal Researcher, Iscte – University Institute of Lisbon

March, 2024

iscte

CIÊNCIAS SOCIAIS
E HUMANAS

Department of Psychology

Correlates of music training: Plasticity or predispositions?

Ana Isabel Costa Correia

PhD in Psychology

Jury:

Professor Margarida Garrido
Associate Professor (with Habilitation), Iscte – University Institute of Lisbon

Dr. Franziska Degè
Research Fellow, Max Planck Institute for Empirical Aesthetics

Dr. Rafael Román Caballero
Post-Doctoral Fellow, McMaster University (Canada) and University of Granada

Professor Rita Jerónimo
Assistant Professor, Iscte – University Institute of Lisbon

Professor César F. Lima
Associate Professor (with Habilitation), Iscte – University Institute of Lisbon

March, 2024

To my first and forever teachers

Acknowledgements

It is with great joy and humility that I start this thesis by recognizing and expressing gratitude for those who contributed with their time and effort to the success of this journey.

First and foremost, I would like to show my deepest appreciation to my supervisors. César, I have always admired your work ethic, your dedication and competence. Thank you for the valuable lessons and the constant encouragement. I would hardly embark on this adventure if it were not for you believing in my potential. Glenn, I am so grateful for your collaboration. Thank you for sharing your expertise with me and for always coming up with new study ideas to keep me busy and productive. I could not dream of a better supervision team.

I would also like to thank Iscte, CIS, and BEC research group for providing the necessary resources and support to conduct this project, as well as continuously promoting learning opportunities to stimulate my professional growth.

I am incredibly grateful for the support and collaboration of my colleagues from Iscte, especially Marta, Leonor, Aíssa, Ricardo, Rafael, and other students and researchers with whom I had the opportunity to work during my PhD. Being part of a team that collaborates on each other's projects helped me develop important research skills and enhanced my overall academic experience.

Speaking of colleagues, I must show my appreciation for my colleagues from Porto, Andreia, Carol, Princie, and Vera. You are the best inheritance from my previous journey. Thank you for being always there, especially for our dinners. Your support was priceless.

I must include in this section my dearest friends, F4, Rubi, Ginny, Deia, Nelinha, Claudinha, Sophie, and all the other friends who shared this journey with me (you are so many!). Thank you for the encouragement, laughter, and love that you never failed to share. I am so lucky that I can't count my true friends on one hand.

Last but definitely not least, I could never go through this journey without the support of my family. Belita and Nelito, God was so generous when he made you my parents, thank you for your unconditional and constant love and encouragement. A special thank you to Maria José for being my family away from home during my stay in Lisbon. This section would not be complete without mentioning my dear brothers, aunts, uncles, cousins, grandparents, and goddaughters. Thank you for always being there, listening, cheering, and making sure I was happy at all times. I am so blessed!

Fundação
para a Ciência
e a Tecnologia

This work was financially supported by national funds through FCT (Portuguese Foundation for Science and Technology) in the scope of a Ph.D. Studentship awarded to A.I.C. (SFRH/BD/148360/2019), a Scientific Employment Stimulus grant awarded to E.G.S. (CEECIND/03266/2018) and a project grant awarded to C.F.L. (PTDC/PSI-GER/28274/2017), and co-funded by the European Regional Development Fund (ERDF) through the Lisbon Regional Operational Program (LISBOA-01-0145-FEDER-028274) and the Operational Program for Competitiveness and Internationalization (POCI-01-0145-FEDER-028274).

Resumo

A possibilidade de o treino musical melhorar competências cognitivas e socioemocionais tem atraído a atenção de investigadores, comunicação social e da população em geral. No entanto, a inconsistência dos resultados e as limitações teóricas e metodológicas dos estudos existentes colocam questões interpretativas. Estudos recentes sugerem que a genética pode influenciar a prática, competência e conquistas musicais, bem como associações entre domínios musicais e não musicais. Embora frequentemente se assuma que a competência musical é resultado do treino musical, ela não é exclusiva dos músicos e varia amplamente na população em geral. Contudo, os correlatos de diferenças individuais nas competências musicais permanecem pouco compreendidos. Num conjunto de cinco estudos, esta tese investigou diferenças individuais na competência musical de indivíduos com e sem treino musical. Examinou-se a forma como estas diferenças individuais se relacionam com variáveis habitualmente estudadas em relação ao treino musical, nomeadamente capacidade cognitiva, reconhecimento de emoções, personalidade, e variáveis sociodemográficas. No Estudo 1, a capacidade de reconhecer emoções vocais evidenciou uma associação fraca com o treino musical, mas forte com as capacidades de perceção musical, independentemente do treino musical. No Estudo 2, o *Musical Ear Test* revelou ser uma ferramenta confiável e válida para avaliar a competência musical online. No Estudo 3, músicos profissionais apresentaram maior competência musical e perfis de personalidade diferentes comparativamente com outros indivíduos, mas não diferiram na capacidade cognitiva. No Estudo 4, as competências musicais mostraram uma associação com a capacidade cognitiva e experiências musicais informais, mas não com traços de personalidade. Além disso, indivíduos sem treino musical mas com boa competência musical tiveram um desempenho semelhante ao de indivíduos com treino musical em termos de capacidade cognitiva, mas obtiveram um valor inferior no traço de personalidade abertura à experiência. No Estudo 5, os participantes foram relativamente capazes de avaliar a sua própria competência musical, embora tendessem a sobrestimá-la, uma tendência que foi mais pronunciada nos homens e em indivíduos com menor capacidade cognitiva. Em geral, a investigação desenvolvida sublinha a importância de considerar a musicalidade de indivíduos sem treino musical, bem como as diferenças entre indivíduos com treino musical, no sentido de melhorar a nossa compreensão das associações entre competências musicais e não musicais.

Palavras-chave: competência musical, treino musical, transferência, capacidade cognitiva, emoção

PsycINFO Classification Categories and Codes:

2326 Auditory & Speech Perception

2340 Cognitive Processes

Abstract

The possibility that music training improves cognitive and socioemotional abilities has captured the attention of researchers, the media, and the general population. Nevertheless, the inconsistency of the results and the theoretical and methodological limitations of the studies raise interpretative issues. Recent studies suggest that genetics might influence musical practice, aptitude, and achievements, as well as associations between musical and nonmusical domains. Although musical ability is often assumed to result from music training, it is not exclusive to musicians and varies widely among the general population, but the correlates of individual differences in musical abilities remain poorly understood. Through a series of five studies, this thesis investigated individual differences in musical ability among musically trained and untrained individuals. It examined how these differences relate to variables that are usually studied in the context of music training, namely cognitive ability, emotion recognition, personality, and sociodemographic variables. In Study 1, the ability to recognize vocal emotions was only weakly associated with music training, but strongly associated with music-perception abilities regardless of music training. In Study 2, the *Musical Ear Test* proved to be a reliable and valid method to assess musical ability online. In Study 3, professional musicians showed enhanced musical ability and different personality profiles compared to other individuals, but they were average in terms of cognitive ability. In Study 4, musical abilities were associated with cognitive ability and informal musical experiences but not with personality traits. Moreover, musically untrained individuals with enhanced musical aptitude performed similarly to trained individuals in cognitive ability, but lower in the personality trait openness-to-experience. In Study 5, participants provided relatively accurate ratings of their own musical ability, even though they tended to over-estimate their ability, a tendency that was exaggerated for men and for individuals with lower cognitive ability. Overall, the present research underscores the importance of considering the musicality of untrained individuals and differences among trained individuals to improve our understanding of associations between musical expertise and nonmusical abilities.

Keywords: musical ability, music training, transfer effects, cognitive ability, emotion

PsycINFO Classification Categories and Codes:

2326 Auditory & Speech Perception

2340 Cognitive Processes

Table of Contents

Index of Tables

Index of Figures

CHAPTER 1

General Introduction

Music is the universal language of mankind.

Henry Wadsworth Longfellow

Music exists in every society and plays a major role in social interactions and emotion regulation. People from different cultures and generations use music to communicate feelings and intentions, regardless of their ability to speak or understand language. Hardly a day goes by in which we do not interact with music in some way, but musical interests and behaviors vary widely across individuals. Although most people engage often in music-related activities, such as listening to music on the radio, attending concerts, or taking music lessons, some people find it difficult to appreciate or enjoy music.

Individual differences in musical interests and behaviors are associated with factors such as genetics, social contexts, and the benefits people experience while playing or listening to music. Twin studies show effects of genetic variation on music-related traits, including the choice of a musical instrument or genre (Mosing & Ullén, 2018), music accomplishments (Hambrick & Tucker-Drob, 2015), and the association between musical practice and ability. A review of the genetic basis of musical abilities also indicates that genetics play a role in singing, music listening, music perception, and musical memory (Tan et al., 2014). From a social perspective, musical behaviors, particularly rhythmic activities such as dance, are thought to promote social bonding, due partly to the power of music to induce emotional states and motivate emotional attachments (Freeman, 2000). According to the Music and Social Bonding hypothesis (Savage et al., 2021), social bonding through music positively influences parental care, chances of mate selection, and group cohesion. Moreover, listening to music and playing a musical instrument are associated with emotional self-regulation, shared social experiences, and self-awareness (e.g., Wesseldijk et al., 2020). Given the universal nature of musical interests, behaviors, and skills, why are some individuals more musical than others?

The overarching aim of this thesis is to examine individual differences in musicality, and the correlates of such differences. The focus is on musically trained and untrained individuals, and specifically on distinctions that have been overlooked in the literature, such as those between professional musicians and musically trained individuals who are not professionals, and among musically untrained individuals who vary in musical ability.

1.1. Defining Musicality

Studying individual differences in musical behaviors requires defining and measuring such behaviors. For example, researchers may be interested in music-listening habits defined as duration of listening per week, or in performance variables such as whether individuals can play a musical instrument or sing, or the number of instruments they play with proficiency. Studies of musical expertise often focus on duration of formal music lessons, or on comparisons between musically trained and untrained individuals (e.g., Bermudez & Zatorre, 2005; Obergfell et al., 2020; Park et al., 2015). Other studies focus on musicality more broadly, examining abilities that are present in all individuals (Honing, 2018), such as the capacity to perceive small differences in melodies or to remember songs. The fact that all individuals are musical to some extent does not exclude a role for innate individual differences. Some people—with or without music lessons—can have a particularly "good ear" for music. Exposure and learning remain important, but these predispositions influence the development of musical expertise, specifically the trajectory of learning and practicing that may lead to high levels of performance (e.g., Olszewska et al., 2021).

Individuals with no formal training in music are typically referred to as *nonmusicians* and considered to be a homogeneous group. This practice reflects a limited view of musicality because it disregards naturally occurring individual differences in musical ability or interests. In fact, musical ability if often considered to be the exclusive skill of musically trained individuals, which explains why the musical ability of musically untrained individuals is often not even assessed. Although formal music training targets the development of musical abilities, enhanced musical skills can be present among individuals with good musical aptitude, or a natural talent for music, even those with no training (e.g., Mosing et al., 2014). The idea of musical aptitude or innate talents in general was largely eschewed in the late 20th century (e.g., Ericsson et al., 1993), until twin studies revealed genetic contributions to musical skills and behaviors, which gave rise to the less nativist term, *musicality*, which everyone possesses to some extent.

New instruments to assess musicality were developed that could be administered to musically trained and untrained children and adults. One widely used self-report questionnaire, the Goldsmiths Musical Sophistication Index (Gold-MSI; Müllensiefen et al., 2014), highlights four major dimensions of musicality in addition to training: engagement in musical activities, music-perception skills, singing abilities, and emotional responses to music. Consideration of musicality as a multifaceted construct corresponded with the change in perspective on musical abilities and achievements in the general population. Nevertheless, when studies examine aspects of musicality other than training, they continue to rely on measures of music-perception ability (e.g., Law & Zentner, 2012; Wallentin et al., 2010), perhaps because the tests are objective and relatively easy to administer. In any event, researchers have also emphasized how social and cultural factors influence people's ideas of musicality, pointing out the distinct value attributed to attitudes, preferences, aptitude, talent, potential, and so on (e.g., Hallam, 2006; Trehub, 2003; Trehub et al., 2015). Overall, these studies draw attention to the multidimensional nature of musicality that characterizes typically developing individuals with or without music lessons, and varies normally like most human traits, such as intelligence or height.

1.2. Music Training Effects

The literature on musical expertise typically focuses on the distinction between musicians and nonmusicians, examining the possibility of differences in brain structure and function, and in musical and nonmusical behaviors. Evidence of advantages for musicians in many domains, such as auditory skills, IQ, and memory (e.g., Kraus & Chandrasekaran, 2010; Schellenberg, 2004; Talamini et al., 2017), motivated proposals that music training has transformative powers.

The term *plasticity* describes changes in behavior and/or brain structure and function that occur as a consequence of experience (e.g., Karbach & Schubert, 2013). The idea that music training has the power to induce plasticity in nonmusical domains is referred to as *transfer*. Transfer occurs when learning in one domain leads to improved performance in another domain, which can be closely related to the original domain of learning (*near transfer*) or considerably different (*far transfer*; Barnett & Ceci, 2002; Detterman, 1993). *Plasticity* and *transfer* are important concepts in the literature on music training. According to behavioral studies that compare musicians and nonmusicians, music-training effects are not limited to near-transfer domains, such as auditory skills and sensorimotor development (e.g., James et al., 2020; Kraus & Chandrasekaran, 2010; Strait & Kraus, 2011). Instead, they are proposed to extend to far-transfer domains including IQ, memory, executive functions, and emotion recognition (e.g., Amer et al., 2013; Criscuolo et al., 2019; Farmer et al., 2020; Lima & Castro, 2011; Moreno et al., 2011; Okada & Slevc, 2018; Schellenberg, 2004; Talamini et al., 2017).

Musically trained and untrained individuals also differ in brain structure and function. In fact, learning to play a musical instrument has often been considered an excellent model to study plasticity (Münte et al., 2002) because it involves the integration of multisensory perception, the motor system, and higher-order cognitive processes (Herholz & Zatorre, 2012, but see Schellenberg, 2015). Cross-sectional studies using different neuroimaging techniques have identified structural and functional brain differences between musicians and nonmusicians, particularly in temporal (e.g., auditory cortex, superior temporal gyrus), frontal (e.g., inferior frontal gyrus, supplementary motor area) and parietal regions (e.g., somatosensory cortex, supramarginal gyrus), as well as in the fiber tracks connecting these regions (for review, see Olszewska et al., 2021).

Because music holds a special place in many people's hearts, it is tempting to think that music training causes positive changes in behavior and the brain. Most studies are cross-sectional, however, thus precluding inferences of causation. Pre-existing individual differences in factors such as cognitive ability, personality, and musical ability might influence individuals' decision to engage in music learning and/or to become a professional musician (Schellenberg, 2020a). Any advantage observed in correlational studies is therefore likely to reflect a gene-environment interaction, such that the magnitude of the putative role of training cannot be determined.

Schellenberg and Lima (2024) suggest that the decision to take music lessons, and the ultimate duration of training, are influenced by preexisting variables, including cognitive ability, natural musical ability, and demographic and personality factors. In line with this hypothesis, studies with children and adolescents have shown that duration of training is predicted by IQ, personality traits (particularly openness-to-experience), and socio-economic factors such as family income and parents' education (Corrigall et al., 2013; Corrigall & Schellenberg, 2015). Studies with random assignment and longitudinal designs are therefore necessary to understand whether observed differences between musicians and nonmusicians are the result of pre-existing differences, musical practice, or an interaction between the two.

Longitudinal studies compare behavioral or brain changes in one group of individuals who engages in a specific experience, such as music training (experimental group), with at least one other *control* group that does not. To attribute the changes unequivocally to the intervention, group assignment needs to be random to avoid the influence of pre-existing factors in individuals' choice of activity, such that all groups are similar at the beginning of the study (e.g., Schellenberg, 2020b). To ensure that the effect is specific to music training, individuals in the control group need to undergo similar training in a domain other than music. If these criteria are met, one can infer that a larger increase in performance over time in the music group compared to the control group was caused by the training.

Actual evidence for such music-induced plasticity and transfer is scarce and mixed. According to recent meta-analyses, music-training effects on perceptual and cognitive abilities are small or null (Bigand & Tillmann, 2022; Cooper, 2020; Neves et al., 2022; Román-Caballero et al., 2022; Sala & Gobet, 2017a, 2017b, 2020). A recent review of music-training studies highlighted numerous problems regarding the methods and interpretations of the findings (Schellenberg & Lima, 2024). On the one hand, such claims are sometimes inferred from studies without random assignment or control groups (e.g., Barbaroux et al. 2019; Hutchins, 2018). On the other hand, when individuals are randomly assigned to music training or a control group, attrition is often high, such that it is difficult to know whether the individuals who dropped out are similar to those who remained in the study, and whether the results would change if they had remained in the sample. Most longitudinal studies have also been conducted with children (e.g., Habibi et al., 2017; Moreno et al., 2014; Tierney et al., 2015; for a review, see Neves et al., 2022), when plasticity is greater and training is expected to have a bigger impact, which makes it impossible to generalize the findings to older age groups. Moreover, because the term *music training* is not clearly defined in the literature, researchers have implemented different types of training across studies, making it difficult to identify specific aspects of training that explain any observed effects.

Another problem concerns the likelihood of far transfer in general. The common elements theory (Thorndike & Woodworth, 1901) proposes that the probability of transfer effects depends on the level of similarity with the original learning experience. Indeed, far transfer is very rare compared to near transfer (see also, Detterman, 1993; Schooler, 1989), a finding that has been confirmed by several studies, reviews, and meta-analyses of learning in multiple domains, including working memory, music, and chess (Donovan et al., 1999; Sala et al., 2019; Sala & Gobet, 2017a). In short, although the possibility of far transfer tends to attract much interest, it is unlikely to be the primary explanation of correlational results. One strategy to move this debate forward is to examine individual differences in musical *ability* that are independent of training, and to ask how such differences relate to variables that are typically studied in the context of music training. If such variables are associated with musical abilities in the absence of training, they cannot be attributed to formal musical lessons.

In sum, the literature on music training often claims that it has both near and far transfer effects. Substantial theoretical and methodological issues raise doubts about the interpretation of existing evidence. Differences between musicians and nonmusicians could stem from predispositions and/or other personal and environmental factors.

1.3. Nature vs. Nurture: The Role of Predispositions

Most behaviors and skills stem from nature and nurture, including reading development (e.g., Logan et al., 2013; Olson et al., 2014), working-memory ability (e.g., Wang & Saudino, 2013), second-language acquisition (e.g., Dewaele, 2009; Rimfeld et al., 2015), and sports (e.g., Baker & Horton, 2004; Tucker & Collins, 2012). It comes as no surprise, then, that twin studies reveal genetic influences on musical practice, achievements, and ability (Hambrick & Tucker-Drob, 2015; Mosing et al., 2014, 2016; Tan et al., 2014). For example, a study of 800 pairs of twins confirmed the role of genetics on practicing music, which, in turn, mediated genetic effects on musical accomplishments (Hambrick & Tucker-Drob, 2015). In other words, genetics has an influence on who engages in musical practice, which, in turn, magnifies its influence on musical accomplishments. In another study of 10,000 twins, identical twins were more similar than fraternal twins in terms of practicing music and its associations with musical ability, yet unshared environmental factors played a minimal role (Mosing et al., 2014).

Reviews on music and genetics (e.g., Tan et al., 2014; Wesseldijk, Ullén et al., 2023) report converging evidence that different genetic components are associated with distinct aspects of musical ability, such as music perception (Mosing et al., 2014; Ullén et al., 2014), singing ability (Granot et al., 2007; Yeom et al., 2022), musical memory (Granot et al., 2007), and absolute pitch (Theusch & Gitschier, 2011). Genetic contributions also influence associations between music and nonmusical domains such as intelligence (Mosing et al., 2016), verbal ability (Wesseldijk, Gordon, et al., 2023) and mental health (Wesseldijk, Lu, et al., 2023). In other words, although nonmusical variables are often associated with musical expertise, these might not stem, either solely or in part, from music training.

Despite increasing evidence for a genetic contribution to musical abilities and accomplishments, the genetic architecture associated with music-related abilities remains poorly understood. Because genes cannot be directly responsible for behavioral results, other sociodemographic and cognitive variables are likely to mediate gene-environment interactions (Gingras et al., 2015, 2018). For instance, personality, general cognitive ability, and motivational factors, which are largely determined by genetics, influence level of engagement in music-related activities, particularly with prolonged musical practice. For personality, individuals with higher levels of openness-to-experience are more likely to engage and persist in music classes and instrumental practice (e.g., Butkovic et al., 2015; Kuckelkorn et al., 2021). Moreover, individuals with enhanced cognitive ability are globally more curious and prone to pursue their interests and talents, including a desire to play music. Such "niche-picking" is determined initially in development by genetically related conspecifics (i.e., parents), but more actively influenced over time by individuals' choices of environments and experiences (Scarr & McCartney, 1983).

In a recent longitudinal study of music training and musical abilities, Kragness et al. (2021) assessed children's musical ability and music training before and after a period of 5 years. As expected, musical ability correlated with music training in both testing periods. When musical ability at pre-test was held constant, the association between music training and musical ability at post-test was no longer significant. In other words, objectively measured musical ability at post-test appeared to be determined solely by ability at pre-test. Moreover, musical ability at pre-test also explained the amount of training that individuals received between the two testing sessions. Because the timeline precluded a causal role for music training, musical ability influenced the likelihood of taking music lessons. In principle, however, an unidentified factor could have influenced individual differences in musicality *and* music training. In any event, becoming a skilled musical performer requires years of deliberate practice (Ericsson et al., 1993) and we know that music training improves musical abilities such as singing, pitch and rhythm processing, as well as the development of musical emotions (for reviews, see Svec, 2018; Trainor & Corrigall, 2010). Nevertheless, such training appears to have a stronger effect for individuals with higher initial levels of natural musical ability (e.g., Ruthsatz et al., 2008).

If music training has a limited effect on music-perception skills, which musical-ability tests typically measure, it seems unlikely that music training would influence skills in nonmusical domains. Indeed, associations between music training and nonmusical abilities can be unreliable. For example, Hansen et al. (2013) failed to replicate the advantage for musicians in verbal or visuospatial working memory. Even though expert musicians differed from nonmusicians on tests of short-term memory (digit span forward) and musical ability, their working-memory scores were similar to those of amateur musicians. Another study compared musicians and nonmusicians in terms of theory of mind and cognitive abilities such as memory, attention, and executive functions (Giovagnoli & Raglio, 2011). The groups did not differ on any task. More recently, a longitudinal study with kindergarteners did not find an association between intensity of training (45 min vs. 90 to 315 min per week) and executive functioning

(Hogan et al., 2018). Similarly tenuous or absent links with music training have been identified for intelligence (Swaminathan et al., 2017) and reading skills (Swaminathan et al., 2018).

Nonmusical abilities that are associated with music training (e.g., speech perception, Shahin, 2011; second-language ability, Chobert & Besson, 2013) can also be associated with individual differences in musical ability among untrained individuals. For example, untrained adults with good musical abilities exhibit enhanced performance on tests of speech perception (Mankel & Bidelman, 2018). In one instance, foreign-language phoneme perception was independent of music training but associated positively with rhythm abilities (Swaminathan & Schellenberg, 2017). For nonverbal intelligence, associations with music training disappear when musical ability and SES are held constant, although the association between musical ability and intelligence remains evident even after controlling for music training and SES (Swaminathan et al., 2017). In other words, high-functioning individuals are also likely to have higher levels of musical ability and to take music lessons. More generally, when music training and musical abilities are considered simultaneously, musical ability can be a better predictor of nonmusical abilities (Swaminathan et al., 2018; Swaminathan & Schellenberg, 2020).

In sum, there are genetic influences on engagement and persistence in musical practice, musical ability and achievements, and associations between music training and nonmusical domains. Preexisting musical abilities can be better than music training at predicting nonmusical benefits. Thus, any advantage for musicians in nonmusical domains could be more a consequence of predispositions than it is of music training.

1.4. Music and Socioemotional Skills

Studies of music and nonmusical abilities tend to focus on cognitive skills, even though music plays a role in emotion regulation (Lonsdale & North, 2011), in inducing positive emotional states (Trost et al., 2017), and in promoting interpersonal connections and prosocial behavior (Tarr et al., 2014). Merriam (1964) describes 10 major functions of music, focusing on cognitive, social, and emotional domains. The first function is emotional expression, which requires the ability to communicate emotions evoked by music. Two other functions relate to aesthetic enjoyment and entertainment, and another four involve social aspects, all of which highlight the relevance of the socioemotional dimension of music (see also Hargreaves & North, 1999). As most people know from personal experience, listening to music can be a simple but effective way to change mood or lower stress levels. The power of music to induce emotional states, regulate one's emotions, and encourage emotional expression and bonding helps to explain music's universality (Swaminathan & Schellenberg, 2015).

Musical engagement and expertise are also associated with increased volume and activity in regions of the brain that are involved in socioemotional processing. A review of the neural effects of music on emotion regulation found that musical traits and experiences (i.e., singing, listening to familiar/preferred music, music improvising) activate brain regions that underlie emotion regulation (Moore, 2013). In one instance, preterm infants received a music intervention or standard care (Sa de Almeida et al., 2020). Afterward, the music group had larger amygdala volumes and enhanced structural maturation of the uncinate fasciculus. The amygdala and uncinate fasciculus are both associated with socioemotional functions, including emotional empathy (Oishi et al., 2015), emotional regulation (e.g., Hein et al., 2018), and socioemotional symptoms in psychiatric disorders, such as depression (Xu et al., 2023) and anxiety (e.g., Baur et al., 2012; Lee & Lee, 2020). In one neuroimaging study of adults, limbic and paralimbic regions, which are related to emotions and the reward system, were more active when participants heard familiar compared to unfamiliar music, whereas cingulate regions and areas of the frontal lobe were more active for liked compared to disliked music (Pereira et al., 2011). Considered jointly, neuroimaging studies suggest that brain regions and networks involved in socioemotional processing are also related to music-related traits or activities, which could explain enhanced maturation of these brain regions in musicians compared to nonmusicians.

Improved socioemotional skills in musicians are also observed at the behavioral level in several social and emotional domains. For example, music training is associated with improvements in empathy (Egermann & McAdams, 2013; King & Waddington, 2018), prosocial skills (Schellenberg et al., 2015; Váradi, 2022), emotional regulation (Moore, 2013; Sakka & Juslin, 2018), and emotion recognition (Thompson et al., 2001). Moreover, socioemotional processing is compromised in individuals with developmental music disorders (Lima et al., 2016; Pralus et al., 2019; Zhou et al., 2019). Most of the relevant studies were cross-sectional, however, such that it remains unknown whether music training produced socioemotional benefits. Alternatively, individuals with enhanced socioemotional skills could be more likely to engage and persist in music classes, or some unidentified variable could be causing these associations.

Existing longitudinal studies are scarce and conducted primarily with children. One study with 3- to 5-year-olds showed improvements in social cooperation, interaction, and independence for those who received music lessons compared to control children who did not receive any training (Ritblatt et al., 2013). Boucher et al. (2021) evaluated the socioemotional skills of 4- and 5-year-olds before and after they participated in a music-training program for 8 to 15 weeks. The training appeared to improve 4-year-olds' social interactions and 5-year-olds' understanding of emotions. The 5-year-olds exhibited *lower* levels of cooperation after training, however, and duration of training had no influence for either age group, which raises the possibility that associations between music training and socioemotional skills are more influenced by age than by duration of training. Moreover, the study had no control groups, such that the results could be a consequence of natural development.

A meta-analysis on the impact of music training on the socioemotional development of young children (< 6 years) concluded that there was a positive but moderate effect size (Gaudette-Leblanc et al., 2021). They also noted the need for more rigorous research protocols that include reliable and valid measures. Moreover, Rose et al. (2019) concluded from parent- and teacher-reports that learning a musical instrument had no effect on the socioemotional wellbeing of children, whereas Schellenberg and Mankarious (2012) found that associations between music training and children's understanding of emotions appear to be explained fully by IQ. Finally, at the end of a 1-year longitudinal study (Thompson et al., 2004), children with keyboard training outperformed children in a passive control group on a test of emotional prosody perception, but they were no different from children in an active (drama) control group, the advantage over passive controls did not extend to children with vocal training, and attrition made the findings difficult to interpret.

In short, findings from studies of children are inconsistent, and evidence from studies of adults is equivocal. For example, among younger and older adults, quasi-experiments indicate that music training is associated positively with emotion recognition (Castro & Lima, 2014; Lima & Castro, 2011), and that singing in a choir predicts benefits in wellbeing and social bonding (e.g., Bullack et al., 2018; Williams et al., 2018). Nevertheless, a review of associations between music training and *hot* executive functions in individuals aged 3 to 85 years old concluded that associations with music training were weak and reliable only for some tasks and age groups (Frischen et al., 2022). Hot executive functions refer to those influenced by emotional and motivational responses that occur in tasks that involve risky decision making (e.g., gambling).

The ability to recognize emotions conveyed by the human voice is central to socioemotional processing. Such recognition is associated positively with socioemotional adjustment in children (e.g., Leppänen & Hietanen, 2001; Neves et al., 2021), but negatively with depressive symptoms in adolescents and adults (e.g., Morningstar et al., 2019; Naranjo et al., 2011).

Although music training can be associated positively with the ability to recognize vocal emotions among children and adults (for a review, see Martins et al., 2021), some results are mixed and difficult to interpret. In one instance (Mualem & Lavidor, 2015), music training was better than art training at improving adults' ability to recognize emotions in a short-term longitudinal study, but there were no differences between musically trained and untrained adults in a correlational study even though trained participants had at least 6 years of lessons.

If musicians' advantage at recognizing vocal emotions extends to untrained individuals with good musical abilities, the role of formal training would be called into question. Rather, predispositions and/or informal musical experiences (e.g., listening attentively to music, attending live concerts, self-learning to play an instrument) would appear to play an important role, and such a result would inform discussions about the possibility of far-transfer effects from music training. More generally, if musical abilities predict nonmusical abilities regardless of training, reported associations with music training would need to be re-examined, particularly because musical ability is rarely measured, and selection criteria for samples of musicians or musically trained participants varies across studies. In short, further research is needed to delineate the roles of music training and musical abilities in associations between musical expertise and socioemotional skills.

1.5. The Musicians: Professionals vs. Amateurs

Research participants tend to be classified as musicians if they studied music in a formal setting for at least a certain number of years. In other words, they are recruited based on the duration of their formal music training (e.g., Battcock & Schutz, 2021; Bermudez & Zatorre, 2005; Clayton et al., 2016). The specific amount of training differs across studies, but a minimum of 6 years is often the rule (Zhang et al., 2020). Although a small minority of musically trained individuals become professional musicians (e.g., music professors, songwriters, members of a band or orchestra), most individuals who take music lessons end up pursuing other careers (e.g., chefs, English teachers, scientific researchers). The distinction between professional musicians and musically trained participants (or *amateurs*; e.g., Kuckelkorn et al., 2021) is typically overlooked despite potential differences in experiences, engagement with music-related activities, and developmental trajectories.

Compared to trained individuals who are not professionals, professional musicians have more musical experience and regular contact with music, in addition to performing music in concerts (e.g., Krampe & Ericsson, 1996; Tervaniemi, 2009). Factors that encourage participants to engage, persist in music training and, ultimately, select a music-related job are likely to include musical abilities. Researchers have reported that, compared to other musically trained and untrained individuals, professional musicians have more motivation to engage in musical activities (Appelgren et al., 2019), more deliberate musical practice (Krampe & Ericsson, 1996), more practice in childhood (Bonde et al., 2018), higher scores on openness-to-experience (Kuckelkorn et al., 2021), better performance on some tests of executive functions (Travis et al., 2011), and more focused cerebral activations in specific areas of the sensorimotor and auditory cortices (Lotze et al., 2003). Many of these findings have not been replicated, however, and further evidence is necessary to confirm differences in musical skills, sociodemographic factors (e.g., socioeconomic status), personality traits, and cognitive abilities.

Some studies have reported that music training enhances cognitive abilities (e.g., Bugaj & Brenner, 2011; Moreno et al., 2011; Román-Caballero et al., 2018; Schellenberg, 2004), and that duration of training has a linear positive association with general cognitive ability for children and adults (e.g., Corrigall et al., 2013; Degé et al., 2011; Schellenberg, 2006; Swaminathan et al., 2017). Should we assume, then, that professional musicians, often with decades of training, are intellectually superior to the average adult? If plasticity is implicated, professionals should outperform other musically trained and untrained individuals on cognitive tests. But if professionals, who have the most musical experiences, are similar to musically trained and untrained individuals, explanations of music-training effects in terms of plasticity and far transfer would be called into question. Personality could also be a distinguishing factor because it predicts career choices (Holland, 1997), and we know that duration of music training is associated positively with openness-to-experience (Butkovic et al., 2015; Kuckelkorn et al., 2021), a personality trait that predicts creativity in general, (Feist, 1998, 2019), as well as musical ability and experience (e.g., Corrigall et al., 2013; Lima et al., 2020).

In short, musically trained individuals are a heterogenous group, varying in terms of current occupation, and history of music learning, performance, and practice. To date, little is known about the correlates of such differences. Examining this issue could improve our understanding of what it means to be a musician and shed light on established associations between music training and nonmusical abilities.

1.6. Nonmusicians: A Heterogenous Group

Although musically untrained individuals are bound to be similarly heterogenous, researchers often consider them simply to be low in terms of musical ability compared to musicians, even though such abilities are evaluated rarely (e.g., Bermudez & Zatorre, 2005; Boebinger et al., 2015). On the one hand, although we associate musical expertise primarily with formal lessons, many individuals (e.g., Paul McCartney) learn how to play music informally by themselves or with friends and family. Moreover, the distinction between formal and informal learning could represent a continuum (Folkestad, 2006; Veblen, 2012). Participants with a history of informal music learning and practice are typically considered to be nonmusicians, but it remains unclear whether the correlates of such informal experience are similar to or distinct from those of formal training. On the other hand, predispositions that determine individual differences in musical abilities have a clear genetic component (e.g., Hambrick & Tucker-Drob, 2015; Tan et al., 2014; Wesseldijk et al., 2019). Some untrained individuals may thus have a natural talent for music, which could be reflected in active engagement in musical activities other than lessons, such as in music-perception skills or singing ability.

Law and Zentner (2012) coined the term *musical sleepers* to describe musically untrained individuals who have good musical abilities. Presumably, these individuals could become proficient musicians with the appropriate opportunity and time. Musical sleepers also provide the opportunity for researchers to understand better how music training and musical ability are related. For example, if some untrained individuals have *musical* abilities that match those of musicians, music training would not be a necessary contributor. Similarly, if musical sleepers have advantages in *nonmusical* abilities that are similar to those of musicians, an exclusive causal role for music training would be precluded. Rather, preexisting differences would be implicated. Conversely, if musicians outperform musical sleepers in nonmusical abilities, music training would appear to play a role, although specific aspects of the training that explain the effects would remain unknown. In one instance, musical sleepers exhibited enhanced neural encoding and perception of speech (Mankel & Bidelman, 2018), which had previously been found for highly trained musicians.

Because studies of musical sleepers are rare, it is unclear how their musical abilities compare to those of trained musicians. Moreover, how would they differ from untrained individuals with low musical skills? In other words, what are the correlates of individual differences in musical ability in the absence of music training? Because factors such as predispositions and informal musical experiences likely play a role in the development of musical abilities and the likelihood of taking music lessons (e.g., Kokotsaki & Hallam, 2011;

McPherson & Hallam, 2016), answering these questions will help to inform debates on the relative contribution of nature and nurture to associations between music training and nonmusical abilities.

Individuals' self-perception of musical abilities could also influence their engagement with music. This is especially relevant when estimations are flawed. For example, if individuals believe incorrectly that they have poor musical skills, they could avoid playing musical instruments, pursuing a music-related job, or choose to pursue careers that do not match their potential. Little is known about this question, however, although a musician's sense of self-efficacy predicts their performance skills better than intensity or duration of formal music learning (McCormick & McPherson, 2003; McPherson & McCormick, 2006; Ritchie & Williamon, 2012). For musically untrained individuals, self-perceptions cannot be based on evaluations of previous performances from self or others (Hendricks, 2016; Zelenak, 2020), except in informal contexts (e.g., dancing at a club, singing at a birthday party). Knowing how self-awareness of musicality relates to actual musical abilities, innate predispositions, and other facets of musical sophistication could improve our understanding of individual differences in musicality, particularly among individuals with no training. This topic is particularly relevant in the Western developed world, where most individuals enjoy music and hear music regularly, yet relatively few become accomplished musicians.

In short, although musically untrained individuals are often treated as a homogeneous group, they are likely to vary widely in terms of musical abilities, just as they vary in height, weight, IQ, and so on. Examining these individual differences will inform our understanding of the correlates of music training and the factors underlying the development of musical expertise.

1.7. Overview of the Thesis

The overall aim of this thesis was to examine the correlates of individual differences in musical expertise among musically trained and untrained individuals. Associations with music training have been studied widely for nonmusical variables such as IQ, personality, and musical experiences. Most studies focused on comparisons between musically trained and untrained individuals, while other potentially relevant distinctions were overlooked, particularly between professional musicians and musically trained individuals who do not become professionals, and between untrained individuals with high or low levels of natural musical ability.

In Chapters 2 to 6, five studies are reported, all of which are currently published in peer-reviewed journals. The first (Chapter 2) examined associations between musical abilities and the ability to recognize vocal emotions in the general population. Although some studies found that musicians have enhanced abilities at recognizing emotions from nonverbal vocal cues, others failed to replicate this result. Our goals were (1) to test whether the association between emotion recognition and music training could be replicated, (2) to explore whether it generalizes across different types of emotional cues (nonverbal vocalizations, speech prosody), (3) to ask whether it is specific to the auditory modality or also evident for visual cues, and (4) to determine whether similar enhancements would be evident for participants with no music training but good musical abilities. Whether the findings prove to be positive or negative, they will improve our knowledge of the socioemotional correlates of musical expertise.

Data collection was shifted subsequently to online testing because of the COVID-19 pandemic, such that it became necessary to adapt measures of musical expertise accordingly. In the second study (Chapter 3), a valid and reliable measure of musical abilities—the Musical Ear Test (MET; Wallentin et al., 2010)—was adapted for online testing using a research platform appropriate for auditory stimuli (Gorilla Experiment Builder). The goals were to validate the instrument, to ensure that it maintained the reliability and validity of the original (in-person) test such that the online version could be used in future studies. Another goal was to test the internal reliability of the online Gold-MSI (Müllensiefen et al., 2014; Portuguese version, Lima et al., 2020).

In the third study (Chapter 4), professional musicians and musically trained and untrained individuals were compared in terms of cognitive ability, personality, demographic variables, and musical abilities. Marked differences between professional musicians and other musically trained participants would raise doubts about the results from studies that considered musically trained individuals to be a homogenous group. The specific goal was to determine whether the enhanced skills of musicians on some tasks are better explained by formal music training or by pre-existing differences (e.g., in personality, cognitive ability or socioeconomic status) that influence their choice to pursue music education or a career in music.

The fourth study (Chapter 5) focused on musically untrained individuals, asking what factors correlate with musical abilities in the absence of formal music training. We considered the role of personality, general cognitive ability, and informal musical experiences such as listening attentively to music, and singing or playing a musical instrument without formal lessons. By delineating similarities and differences between the correlates of music training and the correlates of ability, we sought to distinguish training-related correlates from those that appear to stem from natural abilities.

The fifth study (Chapter 6) examined individual differences in self-awareness of musical abilities in the general population, and how such differences relate to objective performance on measures of musical abilities and experience, personality, general cognitive ability, and sociodemographic variables. Additionally, the study examined biases typically found in studies of self-awareness, namely the better-than-average (Zell et al., 2020) and the male superiority (Cooper et al., 2018; Herbst, 2020) effects.

Chapter 7 provides a general discussion of the results, focusing on the correlates of musical abilities, particularly within groups of musically trained and untrained individuals. Associations among music training, musical abilities, and socioemotional abilities are discussed. The nature vs. nurture debate within the scope of music training and musical abilities is considered in light of evidence from the emotion-recognition study and comparisons of subgroups of musically trained (professionals vs. amateurs) and untrained (higher vs. lower musical abilities) individuals. Two central questions are discussed: are associations between music training and several cognitive and socioemotional skills better explained by training itself or by predispositions? What factors explain musical abilities in the absence of music training? In line with these questions, the possibility of plasticity and transfer effects from music training is examined. The discussion also identifies limitations of the present studies and suggests directions for future research.

Figure 1.1. Overview of the Thesis

Chapter 1 | General Introduction

- Musical abilities vary widely in the general population.
- There is no consensus in the literature regarding the possibility of transfer from music training to cognitive and socioemotional abilities.
- Twin studies suggest that genetics can influence musical practice, ability and achievements, as well as associations between music and nonmusical domains.
- Musicians and nonmusicians are not homogeneous groups, but little is known about individual differences among participants within these groups. A better understanding of such differences will inform debates on what explains the advantages of musicians on musical and nonmusical tasks.

Chapter 2 | Study 1

Title: *Enhanced Recognition of Vocal Emotions in Individuals with Naturally Good Musical Abilities*
Aim: To replicate the effect of music training on vocal emotion recognition; to examine whether it generalizes to different vocal cues and to the visual domain; to understand whether musically talented nonmusicians have the same advantage as musicians in the ability to recognize vocal emotions

Chapter 3 | Study 2

Title: *Can musical ability be tested online?*
Aim: To adapt and validate The Musical Ear Test for online administration

Chapter 4 | Study 3

Title: *Associations Between Music Training and Cognitive Abilities: The Special Case of Professional Musicians*
Aim: To clarify the established association between music training and cognitive ability

Chapter 5 | Study 4

Title: *Individual Differences in Musical Ability among Adults with no Music Training*
Aim: To determine the factors that correlate with musical abilities in the absence of music training

Chapter 6 | Study 5

Title: *Self-awareness of Musical Ability*
Aim: To examine the self-awareness of musical ability in the general population

Chapter 7 | General Discussion

- Genetic predispositions and informal music engagement significantly influence the development of musical abilities, regardless of formal music training.
- Musical abilities is better than music training to explain associations between music and nonmusical domains, which is inconsistent with the idea of transfer effects of music training.
- Individuals within musically trained and untrained groups showed significant variations in terms of musical abilities, cognition, and personality.
- Our studies highlight the need to consider the musicality of untrained individuals and differences among trained individuals to better understand associations between music and nonmusical domains.

References

Amer, T., Kalender, B., Hasher, L., Trehub, S.E., & Wong, Y. (2013). Do older professional musicians have cognitive advantages? *PLoS ONE, 8*(8), e71630. https://doi.org/10.1371/journal.pone.0071630

Appelgren, A., Osika, W., Theorell, T., Madison, G., & Bojner Horwitz, E. (2019). Tuning in on motivation: Differences between non-musicians, amateurs, and professional musicians. *Psychology of Music*, *47*(6), 864–873. https://doi.org/10.1177/0305735619861435

Baker, J., & Horton, S. (2004). A review of primary and secondary influences on sport expertise. *High Ability Studies*, *15*(2), 211–228. https://doi.org/10.1080/1359813042000314781

Barbaroux, M., Dittinger, E., & Besson, M. (2019). Music training with Démos program positively influences cognitive functions in children from low socio-economic backgrounds. *PLOS ONE*, *14*(5). https://doi.org/10.1371/journal.pone.0216874

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn?: A taxonomy for far transfer. *Psychological Bulletin*, *128*(4), 612–637. https://doi.org/10.1037//0033-2909.128.4.612

Battcock, A., & Schutz, M. (2021). Emotion and expertise: How listeners with formal music training use cues to perceive emotion. *Psychological Research*, *86*(1), 66–86. https://doi.org/10.1007/s00426-020-01467-1

Baur, V., Hänggi, J., & Jäncke, L. (2012). Volumetric associations between uncinate fasciculus, amygdala, and trait anxiety. *BMC Neuroscience*, *13*(1). https://doi.org/10.1186/1471-2202-13-4

Bermudez, P., & Zatorre, R. J. (2005). Differences in gray matter between musicians and nonmusicians. *Annals of the New York Academy of Sciences*, *1060*(1), 395–399. https://doi.org/10.1196/annals.1360.057

Bigand, E., & Tillmann, B. (2022). Near and far transfer: Is music special? *Memory & Cognition, 50*(2), 339-347. https://doi.org/10.3758/s13421-021-01226-6

Boebinger, D., Evans, S., Rosen, S., Lima, C. F., Manly, T., & Scott, S. K. (2015). Musicians and nonmusicians are equally adept at perceiving masked speech. *The Journal Of The Acoustical Society Of America*, *137*(1), 378-387. https://doi.org/10.1121/1.4904537

Bonde, L. O., Juel, K., & Ekholm, O. (2018). Associations between music and health-related outcomes in adult non-musicians, amateur musicians and professional musicians—Results from a nationwide Danish study. *Nordic Journal of Music Therapy*, 27(4), 262–282. https://doi.org/10.1080/08098131.2018.1439086

Boucher, H., Gaudette-Leblanc, A., Raymond, J., & Peters, V. (2021). Musical learning as a contributing factor in the development of socio-emotional competence in children aged 4 and 5: An exploratory study in a naturalistic context. *Early Child Development and Care*, *191*(12), 1922–1938. https://doi.org/10.1080/03004430.2020.1862819

Bugaj, K., & Brenner, B. (2011). The effects of music instruction on cognitive development and reading skills—an overview. *Bulletin of the Council for Research in Music Education*, (189), 89–104. https://doi.org/10.5406/bulcouresmusedu.189.0089

Bullack, A., Gass, C., Nater, U. M., & Kreutz, G. (2018). Psychobiological effects of choral singing on affective state, social connectedness, and stress: Influences of singing activity and Time course. *Frontiers in Behavioral Neuroscience*, *12*. https://doi.org/10.3389/fnbeh.2018.00223

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of musical practice: Underlying environmental and genetic influences. *Personality and Individual Differences, 74*, 133–138. https://doi.org/10.1016/j.paid.2014.10.006

Castro, S. L., & Lima, C. F. (2014). Age and musical expertise influence emotion recognition in music. *Music Perception*, *32*(2), 125–142. https://doi.org/10.1525/mp.2014.32.2.125

Chobert, J., & Besson, M. (2013). Musical expertise and Second language learning. *Brain Sciences*, *3*(4), 923–940. https://doi.org/10.3390/brainsci3020923

Clayton, K. K., Swaminathan, J., Yazdanbakhsh, A., Zuk, J., Patel, A. D., & Kidd, G. (2016). Executive function, visual attention and the cocktail party problem in musicians and Non-Musicians. *PLoS ONE*, *11*(7). https://doi.org/10.1371/journal.pone.0157638

Cooper, K. M., Kreig, A., & Brownell, S. E. (2018). Who perceives they are smarter? Exploring the influence of student characteristics on student academic self-concept in physiology. *Advances in Physiology Education,* *42*(2), 200-208. https://doi.org/10.1152/advan.00085.2017

Cooper, P. K. (2020). It's all in your head: A meta-analysis on the effects of music training on cognitive measures in schoolchildren. *International Journal of Music Education*, *38*(3), 321–336. https://doi.org/10.1177/0255761419881495

Corrigall, K. A., & Schellenberg, E. G. (2015). Predicting who takes music lessons: Parent and child characteristics. *Frontiers in Psychology*, *6*, Article 282. https://doi.org/10.3389/fpsyg.2015.00282

Corrigall, K. A., Schellenberg, E. G., & Misura, N. A. (2013). Music training, cognition, and personality. *Frontiers in Psychology*, *4*, Article 222. https://doi.org/10.3389/fpsyg.2013.00222

Criscuolo, A., Bonetti, L., Särkämö, T., Kliuchko, M., & Brattico, E. (2019). On the association between musical training, intelligence and executive functions in adulthood. *Frontiers in Psychology*, *10*, article 1704. https://doi.org/10.3389/fpsyg.2019.01704

Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: A relation mediated by executive functions. *Music Perception, 29*(2), 195–201. https://doi.org/10.1525/mp.2011.29.2.195

Detterman, D. K. (1993). The case for the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 1–24). Ablex Publishing.

Dewaele, J. (2009). Individual differences in second language acquisition. In W. C. Ritchie, & T. K. Bhatia (Eds.), *The New Handbook of Second Language Acquisition* (pp. 623–646). Emerald Group Publishing Limited.

Donovan, M. S., Bransford, J. D., & Pellegrino, J. W. (1999). *How People Learn: Bridging Research and Practice*. National Academy Press.

Egermann, H., & McAdams, S. (2013). Empathy and emotional contagion as a link between recognized and felt emotions in music listening. *Music Perception*, *31*(2), 139–156. https://doi.org/10.1525/mp.2013.31.2.139

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363–406. https://doi.org/10.1037/0033-295X.87.3.215

Farmer, E., Jicol, C., & Petrini, K. (2020). Musicianship enhances perception but not feeling of emotion from others' social interaction through speech prosody. *Music Perception*, *37*(4), 323–338. https://doi.org/10.1525/mp.2020.37.4.323

Feist, G. J. (1998). A meta-analysis of personality in scientific and artistic creativity. *Personality and Social Psychology Review, 2*(4), 290–309. https://doi.org/10.1207/s15327957pspr0204_5

Feist, G. J. (2019). Creativity and the Big Two model of personality: Plasticity and stability. *Current Opinion in Behavioral Sciences, 27*, 31–35. https://doi.org/10.1016/j.cobeha.2018.07.005

Folkestad, G. (2006). Formal and informal learning situations or practices *vs* formal and informal ways of learning. *British Journal of Music Education*, *23*(2), 135-145. https://doi.org/10.1017/s0265051706006887

Freeman, W. J. (2000). A neurobiological role of music in social bonding. In N. L. Wallin, B. Merker, & S. Brown (Eds.), *The Origins of Music* (pp. 411–424). MIT Press.

Frischen, U., Schwarzer, G., & Degé, F. (2022). Music training and executive functions in adults and children: What role do hot executive functions play? *Zeitschrift Für Erziehungswissenschaft*, *25*(3), 551–578. https://doi.org/10.1007/s11618-022-01103-1

Gaudette-Leblanc, A., Boucher, H., Bédard-Bruyère, F., Pearson, J., Bolduc, J., & Tarabulsy, G. M. (2021). Participation in an early childhood music programme and Socioemotional Development: A meta-analysis. *International Journal of Music in Early Childhood*, *16*(2), 131–153. https://doi.org/10.1386/ijmec_00032_1

Gingras, B., Honing, H., Peretz, I., Trainor, L. J., & Fisher, S. E. (2015). Defining the biological bases of individual differences in musicality. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1664), 20140092. https://doi.org/10.1098/rstb.2014.0092

Gingras, B., Honing, H., Peretz, I., Trainor, L. J., & Fisher, S. E. (2018). Defining the biological bases of individual differences in musicality. In H. Honing (Ed.), *The Origins of Musicality* (pp. 221–250). MIT Press. https://doi.org/10.7551/mitpress/10636.003.0015

Giovagnoli, A. R., & Raglio, A. (2011). Cognitive abilities of musicians. *Perceptual and Motor Skills*, *113*(2), 563–569. https://doi.org/10.2466/04.11.22.23.pms.113.5.563-569

Granot, R. Y., Frankel, Y., Gritsenko, V., Lerer, E., Gritsenko, I., Bachner-Melman, R., Israel, S., & Ebstein, R. P. (2007). Provisional evidence that the arginine vasopressin 1A receptor gene is associated with musical memory. *Evolution and Human Behavior*, *28*(5), 313–318. https://doi.org/10.1016/j.evolhumbehav.2007.05.003

Habibi, A., Damasio, A., Ilari, B., Veiga, R., Joshi, A. A., Leahy, R. M., Haldar, J. P., Varadarajan, D., Bhushan, C., & Damasio, H. (2017). Childhood music training induces change in micro and macroscopic brain structure: Results from a longitudinal study. *Cerebral Cortex*, *28*(12), 4336–4347. https://doi.org/10.1093/cercor/bhx286

Hallam, S. (2006). Musicality. In G. E. McPherson (Ed.), *The child as musician: A handbook of musical development* (pp. 93–110). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198530329.003.0005

Hambrick, D. Z., & Tucker-Drob, E. M. (2015). The genetics of music accomplishment: Evidence for gene–environment correlation and interaction. *Psychonomic Bulletin & Review, 22*(1), 112–120. https:// doi.org/10.3758/s13423-014-0671-9

Hansen, M., Wallentin, M., & Vuust, P. (2013). Working memory and musical competence of musicians and non-musicians. *Psychology of Music, 41*(6), 779-793. https://doi.org/10.1177/0305735612452186

Hargreaves, D. J., & North, A. C. (1999). The functions of music in Everyday life: Redefining the social in Music Psychology. *Psychology of Music*, *27*(1), 71–83. https://doi.org/10.1177/0305735699271007

Hein, T. C., Mattson, W. I., Dotterer, H. L., Mitchell, C., Lopez-Duran, N., Thomason, M. E., Peltier, S. J., Welsh, R. C., Hyde, L. W., & Monk, C. S. (2018). Amygdala habituation and uncinate fasciculus connectivity in adolescence: A multi-modal approach. *NeuroImage*, *183*, 617–626. https://doi.org/10.1016/j.neuroimage.2018.08.058

Hendricks, K. S. (2016). The sources of self-efficacy: Education research and implications for music. *Update: Applications of Research in Music Education, 35*(1), 32-38. https://doi.org/10.1177/8755123315576535

Herbst, T. H. H. (2020). Gender differences in self-perception accuracy: The trust gap and the underrepresentation of women leaders in academia. *SA Journal of Industrial Psychology, 46*(1), 1-8. https://doi.org/10.4102/sajip.v46i0.1704

Herholz, S. C., & Zatorre, R. J. (2012). Musical training as a framework for brain plasticity: Behavior, function, and structure. *Neuron*, *76*(3), 486-502. https://doi.org/10.1016/j.neuron.2012.10.011

Hogan, J., Cordes, S., Holochwost, S., Ryu, E., Diamond, A., & Winner, E. (2018). Is more time in general music class associated with stronger extra-musical outcomes in kindergarten? *Early Childhood Research Quarterly*, *45*, 238–248. https://doi.org/10.1016/j.ecresq.2017.12.004

Holland, J. L. (1997). *Making vocational choices: A theory of vocational personalities and work environments* (3rd ed.). Psychological Assessment Resources.

Honing, H. (Ed.). (2018). *The origins of musicality*. MIT Press.

Hutchins, S. (2018). Early childhood music training and associated improvements in music and language abilities. *Music Perception*, *35*(5), 579–593. https://doi.org/10.1525/mp.2018.35.5.579

James, C. E., Zuber, S., Dupuis-Lozeron, E., Abdili, L., Gervaise, D., & Kliegel, M. (2020). How Musicality, Cognition and Sensorimotor Skills Relate in Musically Untrained

Children. *Swiss Journal of Psychology*, *79*(3-4), 101-112. https://doi.org/10.1024/1421-0185/a000238

Karbach, J., & Schubert, T. (2013). Training-induced cognitive and neural plasticity. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00048

King, E., & Waddington, C. (2018). *Music and empathy*. Routledge.

Kokotsaki, D., & Hallam, S. (2011). The perceived benefits of participative music making for non-music University Students: A comparison with music students. *Music Education Research*, *13*(2), 149–172. https://doi.org/10.1080/14613808.2011.577768

Kragness, H. E., Swaminathan, S., Cirelli, L. K., & Schellenberg, E. G. (2021). Individual differences in musical ability are stable over time in childhood. *Developmental Science, 24*(4), e13081. https://doi.org/10.1111/desc.13081

Krampe, R. T., & Ericsson, K. A. (1996). Maintaining excellence: Deliberate practice and elite performance in young and older pianists. *Journal of Experimental Psychology: General, 125*(4), 331–359. https://doi.org/10.1037/0096-3445.125.4.331

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews Neuroscience*, *11*(8), 599-605. https://doi.org/10.1038/nrn2882

Kuckelkorn, K., de Manzano, Ö., & Ullén, F. (2021). Musical expertise and personality—differences related to occupational choice and instrument categories. *Personality and Individual Differences*, *173*, Article 110573. https://doi.org/10.1016/j.paid.2020.110573

Law, L. N. C., & Zentner, M. (2012). Assessing musical abilities objectively: Construction and validation of the Profile of Music Perception Skills. *PLoS ONE*, *7*(12), Article e52508. https://doi.org/10.1371/journal.pone.0052508

Lee, K. S., & Lee, S. H. (2020). White matter-based Structural Brain Network of Anxiety. *Advances in Experimental Medicine and Biology*, 61–70. https://doi.org/10.1007/978-981-32-9705-0_4

Leppänen, J. M., & Hietanen, J. K. (2001). Emotion recognition and social adjustment in school–aged girls and boys. *Scandinavian journal of psychology*, *42*(5), 429-435. https://doi.org/10.1111/1467-9450.00255

Lima, C. F., Brancatisano, O., Fancourt, A., Müllensiefen, D., Scott, S. K., Warren, J. D., & Stewart, L. (2016). Impaired socio-emotional processing in a developmental music disorder. *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep34911

Lima, C. F., & Castro, S. L. (2011). Speaking to the trained ear: Musical expertise enhances the recognition of emotional speech prosody. *Emotion, 11*(5), 1021-1031. https://doi.org/10.1037/a0024521

Lima, C. F., Correia, A. I., Müllensiefen, D., & Castro, S. L. (2020). Goldsmiths Musical Sophistication Index (Gold-MSI): Portuguese version and associations with socio-demographic factors, personality and music preferences. *Psychology of Music*, *48*(3), 376–388. https://doi.org/10.1177/0305735618801997

Logan, J. A., Hart, S. A., Cutting, L., Deater-Deckard, K., Schatschneider, C., & Petrill, S. (2013). Reading development in young children: Genetic and environmental influences. *Child Development*, *84*(6), 2131–2144. https://doi.org/10.1111/cdev.12104

Lonsdale, A. J., & North, A. C. (2011). Why do we listen to music? A uses and gratifications analysis. *British Journal of Psychology*, *102*(1), 108–134. https://doi.org/10.1348/000712610x506831

Lotze, M., Scheler, G., Tan, H.-R. M., Braun, C., & Birbaumer, N. (2003). The musician's brain: Functional imaging of amateurs and professionals during performance and imagery. *NeuroImage*, *20*(3), 1817–1829. https://doi.org/10.1016/j.neuroimage.2003.07.018

Mankel, K., & Bidelman, G. M. (2018). Inherent auditory skills rather than formal music training shape the neural encoding of speech. *Proceedings Of The National Academy Of Sciences USA, 115*(51), 13129-13134. https://doi.org/10.1073/pnas.1811793115

Martins, M., Pinheiro, A. P., & Lima, C. F. (2021). Does music training improve emotion recognition abilities? A critical review. *Emotion Review, 13*(3), 199-210. https://doi.org/10.1177/17540739211022035

McCormick, J., & McPherson, G. (2003). The role of self-efficacy in a musical performance examination: An exploratory structural equation analysis. *Psychology of Music, 31*(1), 37-51. https://doi.org/10.1177/0305735603031001322

McPherson, G. E., & Hallam, S. (2016). Musical potential. In S. Hallam, I. Cross, & M. Thaut (Eds.), *The Oxford handbook of music psychology* (pp. 433–448). Oxford University Press.

McPherson, G. E., & McCormick, J. (2006). Self-efficacy and music performance. *Psychology of music*, *34*(3), 322-336. https://doi.org/10.1177/0305735606064841

Merriam, A. P. (1964). *The Anthropology of Music*. Northwestern University Press

Moore, K. S. (2013). A systematic review on the neural effects of music on Emotion Regulation: Implications for Music Therapy Practice. *Journal of Music Therapy*, *50*(3), 198–242. https://doi.org/10.1093/jmt/50.3.198

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425–1433. https://doi.org/10.1177/0956797611416999

Moreno, S., Lee, Y., Janus, M., & Bialystok, E. (2014). Short-term second language and music training induces lasting functional brain changes in early childhood. *Child Development*, *86*(2), 394–406. https://doi.org/10.1111/cdev.12297

Morningstar, M., Dirks, M. A., Rappaport, B. I., Pine, D. S., & Nelson, E. E. (2019). Associations between anxious and depressive symptoms and the recognition of vocal socioemotional expressions in youth. *Journal of Clinical Child & Adolescent Psychology*, *48*(3), 491-500. https://doi.org/10.1080/15374416.2017.1350963

Mosing, M. A., Madison, G., Pedersen, N. L., Kuja-Halkola, R., & Ullén, F. (2014). Practice does not make perfect: No causal effect of musical practice on music ability. *Psychological Science, 25*(9), 1795–1803. https://doi.org/10.1177/0956797614541990

Mosing, M. A., Madison, G., Pedersen, N. L., & Ullén, F. (2016). Investigating cognitive transfer within the framework of musical practice: Genetic pleiotropy rather than causality. *Developmental Science, 19*(3), 504–512. https://doi.org/10.1111/desc.12306

Mosing, M. A., & Ullén, F. (2018). Genetic influences on musical specialization: A twin study on choice of instrument and music genre. *Annals of the New York Academy of Sciences, 1423*, 427–434. https://doi.org/10.1111/nyas.13626

Mualem, O., & Lavidor, M. (2015). Music education intervention improves vocal emotion recognition. *International Journal Of Music Education*, *33*(4), 413-425. https://doi.org/10.1177/0255761415584292

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE*, *9*(2), Article e89642. https://doi.org/10.1371/journal.pone.0089642

Münte, T. F., Altenmüller, E., & Jäncke, L. (2002). The musician's brain as a model of neuroplasticity. *Nature Reviews Neuroscience*, *3*(6), 473–478. https://doi.org/10.1038/nrn843

Naranjo, C., Kornreich, C., Campanella, S., Noël, X., Vandriette, Y., Gillain, B., de Longueville, X., Delatte, B., Verbanck, P., & Constant, E. (2011). Major depression is associated with impaired processing of emotion in music as well as in facial and vocal stimuli. *Journal of Affective Disorders*, *128*(3), 243–251. https://doi.org/10.1016/j.jad.2010.06.039

Neves, L., Correia, A. I., Castro, S. L., Martins, D., & Lima, C. F. (2022). Does music training enhance auditory and linguistic processing? A systematic review and meta-analysis of behavioral and brain evidence. *Neuroscience & Biobehavioral Reviews*, *140*, 104777. https://doi.org/10.1016/j.neubiorev.2022.104777

Neves, L., Martins, M., Correia, A. I., Castro, S. L., & Lima, C. F. (2021). Associations between vocal emotion recognition and socio-emotional adjustment in children. *Royal Society Open Science*, *8*(11). https://doi.org/10.1098/rsos.211412

Obergfell, A. L., Schmidt, B. M., Stenneken, P., Wittemann, S. K., & Schabmann, A. (2020). Prosodic sensitivity and reading fluency of musicians and non-musicians. *Reading and Writing*, *34*(4), 887–909. https://doi.org/10.1007/s11145-020-10096-4

Oishi, K., Faria, A. V., Hsu, J., Tippett, D., Mori, S., & Hillis, A. E. (2014). Critical role of the right uncinate fasciculus in emotional empathy. *Annals of Neurology*, *77*(1), 68–74. https://doi.org/10.1002/ana.24300

Okada, B.M., & Slevc, L. R. (2018). Individual differences in musical training and executive functions: a latent variable approach. *Memory and Cognition, 46*(7), 1076–1092. https://doi.org/10.3758/s13421-018-0822-8.

Olson, R. K., Keenan, J. M., Byrne, B., & Samuelsson, S. (2014). Why do children differ in their development of reading and related skills? *Scientific Studies of Reading*, *18*(1), 38–54. https://doi.org/10.1080/10888438.2013.800521

Olszewska, A. M., Gaca, M., Herman, A. M., Jednoróg, K., & Marchewka, A. (2021). How musical training shapes the adult brain: Predispositions and neuroplasticity. *Frontiers in Neuroscience*, *15*. https://doi.org/10.3389/fnins.2021.630829

Park, M., Gutyrchik, E., Welker, L., Carl, P., Poppel, E., Zaytseva, Y., Meindl, T., Blautzik, J., Reiser, M., & Bao, Y. (2015). Sadness is unique: neural processing of emotions in speech prosody in musicians and nonmusicians. *Frontiers in Human Neuroscience, 8,* 1-8. https://doi.org/10.3389/fnhum.2014.01049

Pereira, C. S., Teixeira, J., Figueiredo, P., Xavier, J., Castro, S. L., & Brattico, E. (2011). Music and emotions in the brain: Familiarity matters. *PLoS ONE*, *6*(11). https://doi.org/10.1371/journal.pone.0027241

Pralus, A., Fornoni, L., Bouet, R., Gomot, M., Bhatara, A., Tillmann, B., & Caclin, A. (2019). Emotional prosody in congenital amusia: Impaired and spared processes. *Neuropsychologia*, *134*, 107234. https://doi.org/10.1016/j.neuropsychologia.2019.107234

Ritblatt, S., Longstreth, S., Hokoda, A., Cannon, B.-N., & Weston, J. (2013). Can music enhance school-readiness socioemotional skills? *Journal of Research in Childhood Education*, *27*(3), 257–266. https://doi.org/10.1080/02568543.2013.796333

Rimfeld, K., Dale, P. S., & Plomin, R. (2015). How specific is Second language-learning ability? A twin study exploring the contributions of first language achievement and intelligence to Second language achievement. *Translational Psychiatry*, *5*(9). https://doi.org/10.1038/tp.2015.128

Ritchie, L., & Williamon, A. (2012). Self-efficacy as a predictor of musical performance quality. *Psychology of Aesthetics, Creativity, and the Arts*, *6*(4), 334. https://doi.org/10.1037/a0029619

Román-Caballero, R., Arnedo, M., Triviño, M., & Lupiáñez, J. (2018). Musical practice as an enhancer of cognitive function in healthy aging—A systematic review and meta-analysis. *PLOS One, 13*(11), e0207957. https://doi.org/10.1371/journal.pone.0207957

Román-Caballero, R., & Lupiáñez, J. (2022). Suggestive but not conclusive: An independent meta-analysis on the auditory benefits of learning to play a musical instrument. Commentary on Neves et al. (2022). *Neuroscience & Biobehavioral Reviews, 142*, 104916. https://doi.org/10.1016/j.neubiorev.2022.104916

Rose, D., Jones Bartoli, A., & Heaton, P. (2019). Measuring the impact of musical learning on cognitive, behavioural and socio-emotional wellbeing development in children. *Psychology of Music*, *47*(2), 284–303. https://doi.org/10.1177/0305735617744887

Ruthsatz, J., Detterman, D., Griscom, W. S., & Cirullo, B. A. (2008). Becoming an expert in the musical domain: It takes more than just practice. *Intelligence*, *36*(4), 330–338. https://doi.org/10.1016/j.intell.2007.08.003

Sa de Almeida, J., Lordier, L., Zollinger, B., Kunz, N., Bastiani, M., Gui, L., Adam-Darque, A., Borradori-Tolsa, C., Lazeyras, F., & Hüppi, P. S. (2020). Music enhances structural maturation of emotional processing neural pathways in very preterm infants. *NeuroImage*, *207*, 116391. https://doi.org/10.1016/j.neuroimage.2019.116391

Sakka, L. S., & Juslin, P. N. (2018). Emotion regulation with music in depressed and non-depressed individuals: Goals, strategies, and mechanisms. *Music & Science, 1*, 1–12. https://doi.org/10.1177/2059204318755023

Sala, G., Aksayli, N. D., Tatlidil, K. S., Tatsumi, T., Gondo, Y., & Gobet, F. (2019). Near and far transfer in cognitive training: A second-order meta-analysis. *Collabra: Psychology*, *5*(1). https://doi.org/10.1525/collabra.203

Sala, G., & Gobet, F. (2017a). Does far transfer exist? Negative evidence from chess, music, and working memory training. *Current Directions in Psychological Science, 26*(6), 515-520. https://doi.org/10.1177/0963721417712760

Sala, G., & Gobet, F. (2017b). When the music's over. Does music skill transfer to children's and young adolescents' cognitive and academic skills? A meta-analysis. *Educational Research Review, 20*, 55-67. https://doi.org/10.1016/j.edurev.2016.11.005

Sala, G., & Gobet, F. (2020). Cognitive and academic benefits of music training with children: A multilevel meta-analysis. *Memory & Cognition, 48*(8), 1429–1441. https://doi.org/10.3758/s13421-020-01060-2

Savage, P. E., Loui, P., Tarr, B., Schachner, A., Glowacki, L., Mithen, S., & Fitch, T. (2021). Music as a coevolved system for social bonding, *Behavioral and Brain Sciences, 44,* e59. https://doi.org/10.1017/S0140525X20000333

Scarr, S., & McCartney, K. (1983). How people make their own environments: A theory of genotype → environment effects. *Child Development, 54*(2), 424-435. https://doi.org/10.2307/1129703

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology*, *98*(2), 457–468. https://doi.org/10.1037/0022-0663.98.2.457

Schellenberg, E. G. (2004). Music lessons enhance IQ. *Psychological Science*, *15*(8), 511–514. https://doi.org/10.1111/j.0956-7976.2004.00711.x

Schellenberg, E. G. (2020a). Correlation = causation? music training, psychology, and neuroscience. *Psychology of Aesthetics, Creativity, and the Arts*, *14*(4), 475–480. https://doi.org/10.1037/aca0000263

Schellenberg, E. G. (2020b). Music training, individual differences, and plasticity. In M. S. C. Thomas, D. Mareschal, & I. Dumontheil (Eds.), *Educational neuroscience: Development across the life span* (pp. 415–441). Routledge/Taylor & Francis Group. https://doi.org/10.4324/9781003016830-21

Schellenberg, E. G., Corrigall, K., Dys, S., & Malti, T. (2015). Group music training and children's prosocial skills. *PLOS ONE, 10*(10), e0141449. https://doi.org/10.1371/journal.pone.0141449

Schellenberg, E. G., & Lima, C. F. (2024). Music Training and Nonmusical Abilities. *Annual Review of Psychology, 75*. https://doi.org/10.1146/annurev-psych-032323-051354

Schellenberg, E. G., & Mankarious, M. (2012). Music training and emotion comprehension in childhood. *Emotion, 12*(5), 887–891. https://doi.org/10.1037/a0027971

Shahin, A. J. (2011). Neurophysiological influence of musical training on speech perception. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00126

Strait, D. L., & Kraus, N. (2011). Can you hear me now? Musical training shapes functional brain networks for selective auditory attention and hearing speech in noise. *Frontiers in Psychology, 2*, 1–10. https://doi.org/10.3389/fpsyg.2011.00113

Svec, C. L. (2018). The effects of instruction on the singing ability of children ages 5 to 11: A meta-analysis. *Psychology of Music*, *46*(3), 326–339. https://doi.org/10.1177/0305735617709920

Swaminathan, S., & Schellenberg, E. G. (2015). Current emotion research in music psychology. *Emotion Review*, *7*(2), 189–197. https://doi.org/10.1177/1754073914558282

Swaminathan, S., & Schellenberg, E. G. (2017). Musical competence and phoneme perception in a foreign language. *Psychonomic Bulletin & Review*, *24*(6), 1929–1934. https://doi.org/10.3758/s13423-017-1244-5

Swaminathan, S., & Schellenberg, E. G. (2020). Musical ability, music training, and language ability in childhood. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *46*(12), 2340–2348. https://doi.org/10.1037/xlm0000798

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude? *Intelligence*, *62*, 119–124. https://doi.org/10.1016/j.intell.2017.03.005

Swaminathan, S., Schellenberg, E. G., & Venkatesan, K. (2018). Explaining the association between music training and reading in adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*(6), 992–999. https://doi.org/10.1037/xlm0000493

Talamini, F., Altoè, G., Carretti, B., & Grassi, M. (2017). Musicians have better memory than nonmusicians: A meta-analysis. *Plos ONE*, *12*(10). https://doi.org/10.1371/journal.pone.0186773

Tan, Y. T., McPherson, G. E., Peretz, I., Berkovic, S. F., & Wilson, S. J. (2014). The genetic basis of music ability. *Frontiers in Psychology,* *5*:658. https://doi.org/10.3389/fpsyg.2014.00658

Tarr, B., Launay, J., & Dunbar, R. I. (2014). Music and social bonding: "self-other" merging and neurohormonal mechanisms. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01096

Tervaniemi, M. (2009). Musicians—same or different? *Annals of the New York Academy of Sciences*, *1169*(1), 151–156. https://doi.org/10.1111/j.1749-6632.2009.04591.x

Theusch, E., & Gitschier, J. (2011). Absolute pitch twin study and segregation analysis. *Twin Research and Human Genetics*, *14*(2), 173–178. https://doi.org/10.1375/twin.14.2.173

Thompson, W. F., Schellenberg, E. G., & Husain G. (2001). Arousal, mood, and the Mozart effect. *Psychological Science, 12*(3), 248–251. https://doi.org/10.1111/1467-9280.00345

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2004). Decoding speech prosody: Do music lessons help?. *Emotion*, *4*(1), 46-64. https://doi.org/10.1037/1528-3542.4.1.46

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. (I). *Psychological Review, 8*(3), 247–261. https://doi.org/10.1037/h0074898

Tierney, A. T., Krizman, J., & Kraus, N. (2015). Music training alters the course of adolescent auditory development. *Proceedings of the National Academy of Sciences*, *112*(32), 10062–10067. https://doi.org/10.1073/pnas.1505114112

Trainor, L. J., & Corrigall, K. A. (2010). Music acquisition and effects of musical experience. In M. R. Jones, R. R. Fay, & A. N. Popper (Eds.), *Music perception* (pp. 89–127). Springer Science + Business Media. https://doi.org/10.1007/978-1-4419-6114-3_4

Travis, F., Harung, H. S., & Lagrosen, Y. (2011). Moral Development, executive functioning, peak experiences and brain patterns in professional and amateur classical musicians: Interpreted in light of a unified theory of performance. *Consciousness and Cognition*, *20*(4), 1256–1264. https://doi.org/10.1016/j.concog.2011.03.020

Trehub, S. E. (2003). The developmental origins of musicality. *Nature Neuroscience*, *6*(7), 669–673. https://doi.org/10.1038/nn1084

Trehub, S. E., Becker, J., & Morley, I. (2015). Cross-cultural perspectives on music and musicality. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1664), 20140096. https://doi.org/10.1098/rstb.2014.0096

Trost, W. J., Labbé, C., & Grandjean, D. (2017). Rhythmic entrainment as a musical affect induction mechanism. *Neuropsychologia*, *96*, 96–110. https://doi.org/10.1016/j.neuropsychologia.2017.01.004

Tucker, R., & Collins, M. (2012). What makes champions? A review of the relative contribution of genes and training to sporting success. *British Journal of Sports Medicine*, *46*(8), 555–561. https://doi.org/10.1136/bjsports-2011-090548

Ullén, F., Mosing, M. A., Holm, L., Eriksson, H., & Madison, G. (2014). Psychometric properties and heritability of a new online test for musicality, the Swedish Musical Discrimination Test. *Personality and Individual Differences, 63*, 87–93. http://dx.doi.org/10.1016/j.paid.2014.01.057

Váradi, J. (2022). A review of the literature on the relationship of music education to the development of socio-emotional learning. *SAGE Open*, *12*(1), 215824402110685. https://doi.org/10.1177/21582440211068501

Veblen, K. K. (2012). Adult music learning in formal, informal, and nonformal contexts. In G. E. McPherson & G. F. Welch (Eds.), *The Oxford handbook of music education* (Vol. 2; pp. 243–256). Oxford University Press.

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010). The Musical Ear Test, a new reliable test for measuring musical competence. *Learning and Individual Differences*, *20*(3), 188–196. https://doi.org/10.1016/j.lindif.2010.02.004

Wang, M., & Saudino, K. J. (2013). Genetic and environmental influences on individual differences in emotion regulation and its relation to working memory in toddlerhood. *Emotion, 13*(6), 1055–1067. https://doi.org/10.1037/a0033784

Wesseldijk, L. W., Gordon, R. L., Mosing, M. A., & Ullén, F. (2023). Music and verbal ability—a twin study of genetic and environmental associations. *Psychology of Aesthetics, Creativity, and the Arts*, *17*(6), 675–681. https://doi.org/10.1037/aca0000401

Wesseldijk, L. W., Mosing, M. A., & Ullén, F. (2019). Gene–environment interaction in expertise: The importance of childhood environment for musical achievement. *Developmental Psychology, 55*(7), 1473–1479. https://doi.org/10.1037/dev0000726

Wesseldijk, L. W., Lu, Y., Karlsson, R., Ullén, F., & Mosing, M. A. (2023). A comprehensive investigation into the genetic relationship between music engagement and mental health. *Translational Psychiatry*, *13*(1). https://doi.org/10.1038/s41398-023-02308-6

Wesseldijk, L. W., Ullén, F., & Mosing, M. A. (2020). Does listening to music increase your ability to discriminate musical sounds? *Personality and Individual Differences*, *161*, 110001. https://doi.org/10.1016/j.paid.2020.110001

Wesseldijk, L. W., Ullén, F., & Mosing, M. A. (2023). Music and Genetics. *Neuroscience and biobehavioral reviews*, *152*, 105302. https://doi.org/10.1016/j.neubiorev.2023.105302

Williams, E., Dingle, G. A., & Clift, S. (2018). A systematic review of mental health and wellbeing outcomes of group singing for adults with a mental health condition. *European Journal of Public Health*, *28*(6), 1035–1042. https://doi.org/10.1093/eurpub/cky115

Xu, E. P., Nguyen, L., Leibenluft, E., Stange, J. P., & Linke, J. O. (2023). A meta-analysis on the uncinate fasciculus in depression. *Psychological Medicine*, *53*(7), 2721–2731. https://doi.org/10.1017/s0033291723000107

Yeom, D., Tan, Y. T., Haslam, N., Mosing, M. A., Yap, V. M. Z., Fraser, T., Hildebrand, M. S., Berkovic, S. F., McPherson, G. E., Peretz, I., & Wilson, S. J. (2022). Genetic factors and shared environment contribute equally to objective singing ability. *iScience*, *25*(6), 104360. https://doi.org/10.1016/j.isci.2022.104360

Zelenak, M. S. (2020). Developing self-efficacy to improve music achievement. *Music Educators Journal, 107*(2), 42-50. https://doi.org/10.1177/0027432120950812

Zell, E., Strickhouser, J. E., Sedikides, C., & Alicke, M. D. (2020). The better-than-average effect in comparative self-evaluation: A comprehensive review and meta-analysis. *Psychological Bulletin, 146*(2), 118–149. https://doi.org/10.1037/bul0000218

Zhang, J. D., Susino, M., McPherson, G. E., & Schubert, E. (2020). The definition of a musician in music psychology: A literature review and the six-year rule. *Psychology of Music, 48*(3), 389–409. https://doi.org/10.1177/0305735618804038

Zhou, L., Liu, F., Jiang, J., & Jiang, C. (2019). Impaired emotional processing of chords in congenital amusia: Electrophysiological and behavioral evidence. *Brain and Cognition*, *135*, 103577. https://doi.org/10.1016/j.bandc.2019.06.001

CHAPTER 2

Enhanced Recognition of Vocal Emotions in Individuals with Naturally Good Musical Abilities

Correia, A. I., Castro, S. L., MacGregor, C., Müllensiefen, D., Schellenberg, E. G., & Lima, C. F. (2022). Enhanced recognition of vocal emotion in individuals with naturally good musical abilities. *Emotion, 22*(5), 894-906. http://dx.doi.org/10.1037/emo0000770

Abstract

Music training is widely assumed to enhance several nonmusical abilities, including speech perception, executive functions, reading, and emotion recognition. This assumption is based primarily on cross-sectional comparisons between musicians and nonmusicians. It remains unclear, however, whether training itself is necessary to explain the musician advantages, or whether factors such as innate predispositions and informal musical experience could produce similar effects. Here, we sought to clarify this issue by examining the association between music perception abilities and vocal emotion recognition. The sample (N = 169) comprised musically trained and untrained listeners who varied widely in their musical skills, as assessed through self-report and performance-based measures. The emotion recognition tasks required listeners to categorize emotions in nonverbal vocalizations (e.g., laughter, crying) and in speech prosody. Music training was associated positively with emotion recognition across tasks, but the effect was small. We also found a positive association between music perception abilities and emotion recognition in the entire sample, even with music training held constant. In fact, untrained participants with good musical abilities were as good as highly trained musicians at recognizing vocal emotions. Moreover, the association of music training with emotion recognition was fully mediated by auditory and music perception skills. Thus, in the absence of formal music training, individuals who were 'naturally' musical showed musician-like performance at recognizing vocal emotions. These findings highlight an important role for predispositions and informal musical experience in associations between musical and nonmusical domains.

Keywords: emotion, music, training, aptitude, voice

2.1. Introduction

Much attention has been devoted to the possibility of associations between musical experience and nonmusical abilities, including speech perception (e.g., Coffey et al., 2017), reading ability (e.g., Moreno et al., 2009; Swaminathan et al., 2018), phonological awareness (e.g., Degé & Schwarzer, 2011; Moritz et al., 2012), working memory (e.g., Roden et al., 2014), executive functions (Moreno et al., 2011; Slevc et al., 2016), IQ (e.g., Schellenberg, 2011), and the perception of speech prosody (e.g., Marques et al., 2007; Schön et al., 2004). It is often assumed that music training has the power to improve these abilities (e.g., Kraus & Chandrasekaran, 2010; Moreno & Bidelman, 2014; Patel, 2014; Herholz & Zatorre, 2012). In other words, changes in a musician's brain and behavior would have *far transfer* effects, meaning that they lead to better performance on tasks that are not related to music.

Evidence for far transfer comes primarily from cross-sectional comparisons between classically trained musicians and individuals without training, so-called nonmusicians (e.g., Lima & Castro, 2011; Pinheiro et al., 2015; Schön et al., 2004; Wong et al., 2007). It also comes from a few longitudinal studies, though evidence from these tends to be weak and more likely to be associated with suboptimal designs (e.g., Sala & Gobet, 2017a, 2017b). Longitudinal studies are typically conducted with children in educational contexts, in which music training programs are compared against no training or training in other domains, such as visual arts (Habibi et al., 2016; Moreno et al., 2009; Moreno et al., 2011; Schellenberg et al., 2015; Thompson et al., 2004).

Studying associations between music training and nonmusical variables helps to inform debates on learning and development, and to improve our understanding of how music relates to other domains at behavioral, cognitive, and brain levels (e.g., Patel, 2014; Peretz & Coltheart, 2003). The primary focus on music *training* reflects a narrow view of musicality, however, because musical skills are diverse and determined by multiple factors other than formal lessons. For example, sophisticated musical abilities can be seen in individuals without any training, and such abilities must be a consequence of informal engagement with music and/or musical predispositions (Bigand & Poulin-Charronnat, 2006; Mankel & Bidelman, 2018; Mosing et al., 2014; Swaminathan & Schellenberg, 2018). Indeed, recent perspectives on musicality consider a broad range of musical behaviors and skills beyond playing an instrument or taking classes (e.g., informal listening experience; functional uses of music in everyday life; singing along with tunes; Honing, 2019; Krishnan et al., 2018; Müllensiefen et al., 2014).

Factors other than formal instruction could therefore account for the musician advantages reported in the literature. Enhanced capacities of trained individuals might be induced by training, but they could also reflect genetic variables, early informal engagement with music, or facets of musical experience unrelated to formal training per se (as well as more general cognitive, socio-economic or personality variables; e.g., Swaminathan & Schellenberg, 2018). To distinguish between training itself and these other factors, it is important to study the musical abilities of nonmusicians, and to identify individuals with good abilities despite not being trained. Recent evidence indicates that good music perception skills are associated with good performance in nonmusical domains, regardless of training. For example, such individuals exhibit enhanced phoneme perception in a foreign language (Swaminathan & Schellenberg, 2017) and more efficient neural encoding of speech (Mankel & Bidelman, 2018), mirroring the benefits observed in trained musicians. In short, formal training might not be necessary, or at least not the only factor accounting for the musician advantages in nonmusical domains.

In the present study, we focused on the association between music and one aspect of socio-emotional processing, namely the recognition of emotions in vocal expressions. Although music and musical activities are fundamentally linked to socio-emotional processes (e.g., Koelsch, 2014; Clark et al., 2015), this topic remains much less explored than associations with domains such as executive functions (e.g., Moreno et al., 2011; Slevc et al., 2016) or speech processing (e.g., Madsen et al., 2019; Mankel & Bidelman, 2018). Some evidence indicates that trained musicians outperform untrained individuals in their ability to recognize emotions in speech prosody, that is, emotional states expressed through a speaker's use of pitch, loudness, timing, and timbre cues in speech (Lima & Castro, 2011; Thompson et al., 2004). Other evidence documents that music training predicts efficient low-level neural encoding (auditory brainstem responses) of purely nonverbal vocalizations such as crying (Strait et al., 2009). Neurocognitive pathways for processing music and vocal emotions may overlap, such that formal training in music improves vocal emotional communication in typical and atypical populations (Good et al., 2017).

One possible mechanism is that music training fine-tunes auditory-perceptual abilities that are useful for sensory aspects of voice perception (e.g., pitch and temporal processing). Patel's OPERA hypothesis (2011, 2014) uses this view as an explanation for transfer effects from music to speech processing. Another possibility is that because social-emotional interactions are a central component of many musical activities, higher-order aspects of vocal emotional processing are improved by training because the code for music and vocal emotions is at least partly shared (Juslin & Laukka, 2003; see also Clark et al.2015; Koelsch, 2014; Koelsch, 2015;

Pinheiro et al., 2015). Nevertheless, a musician advantage in emotion recognition is not always evident (Park et al., 2015; Trimmer & Cuddy, 2008), and this issue is typically explored in cross-sectional studies that do not take into account individual differences in musical abilities, particularly in nonmusicians. It remains therefore unclear whether training itself is necessary to drive the putative advantage, or whether musical predispositions and informal engagement with music could produce similar effects.

In the present investigation, our sample of listeners included highly trained musicians and a large number of individuals with minimal or no music training, who were assessed in detail about their music perception abilities, behaviors, and experiences. Our goals were to determine if the advantage for musicians in vocal emotion recognition could be replicated, and to examine the potential role of 'natural' individual differences in musical abilities. Specifically, we asked whether having good listening skills, as identified in musical and non-musical tasks, could also predict the ability to recognize vocal emotions, regardless of music training. In other words, could musically adept individuals with no training approach performance levels similar to those of musicians?

Musical skills, behaviors, and experience were assessed using the Goldsmiths Musical Sophistication Index, Gold-MSI (Müllensiefen et al., 2014; Portuguese version, Lima et al., 2018). The Gold-MSI is a self-report tool designed to evaluate music training, music perception abilities, active engagement with music, singing abilities, and emotional responses to music in the general population. Performance-based auditory and music perception tasks were also included, which indexed pitch discrimination, duration discrimination, beat perception, and melodic memory. Our outcome measures focused on two sources of nonverbal emotional information in the human voice (e.g., Brück et al., 2011; Scott et al., 2010). One was the ability to decode emotions conveyed through prosody in actual speech; the other was the ability to decode emotions conveyed by nonverbal vocalizations (e.g., laughter, crying). Although both prosody and nonverbal vocalizations are vocal signals, their underlying production and perception mechanisms are partly distinct (Pell et al., 2015; Scott et al., 2010). Combining them within the same design allowed us to determine whether associations with music reflect an effect that is specific to prosody, or an effect that extends to the recognition of vocal emotions more generally. Previous research in the area has mostly relied on prosodic stimuli (Lima & Castro, 2011; Pinheiro et al., 2015; Thompson et al., 2004; Park et al., 2015; Trimmer & Cuddy, 2008).

We predicted that music training would be associated positively with vocal emotion recognition, both for prosody and nonverbal vocalizations, which would represent a replication and extension of previous findings (Lima & Castro, 2011; Thompson et al., 2004). We also expected that auditory and music perception skills would be positively correlated with the ability to recognize vocal emotions, even after accounting for music training. This hypothesis was based on evidence of enhancements in phoneme perception and speech processing in untrained individuals with good music perception skills (Mankel & Bidelman, 2018; Swaminathan & Schellenberg, 2017). Because domain-general cognitive abilities predict both music training *and* music perception skills (Swaminathan & Schellenberg, 2018), a digit-span task was included to examine whether observed associations were simply a by-product of general factors.

More exploratory questions asked whether the link between music and emotion recognition is specific to audition. Lima et al. (2016) identified that individuals with congenital amusia (i.e., a music disorder present throughout development) have deficits in identifying emotions expressed vocally *and* visually through facial expressions. Nevertheless, the role of individual differences in musical abilities among typically developing individuals remains unknown. We also asked whether other aspects of musical expertise and experience (i.e., active engagement with music, singing abilities, emotions) are associated with vocal emotional processing. Finally, we examined whether any association between music training and vocal emotions is mediated by perceptual skills (music training → perceptual skills → vocal emotion recognition). Complete mediation would imply that the association depends primarily on relatively low-level listening skills, which music training may enhance. By contrast, partial or no mediation would imply that the association between music and vocal emotions is also driven by non-perceptual processes, possibly at higher-order cognitive or social levels (e.g., emotional and social components of music activities).

2.2. Method

Ethical approval for the study protocol was obtained from the Departmental Ethics Committee, Faculty of Psychology and Education Sciences, University of Porto (reference 3-1/2017). Written informed consent was collected from all participants, who were either paid or given partial course credit.

2.2.1. Participants

A total of 172 participants were recruited from research participant pools or in response to advertisements on campus or on social media. Three were excluded for not completing the

Gold-MSI, which resulted in a final sample of 169 (116 female). Participants were 23.49 years of age on average (*SD* = 8.27, Range: 18 - 72). According to self-reports, all participants had normal hearing and no history of neurological or psychiatric disorders, and all were native speakers of European Portuguese. Formal music training varied widely, as illustrated in Figure 1. The mode was no training (n = 69), but 100 had some training, ranging from 0.5 to 10 or more years. Duration of music training was not associated with age (r = -.01, p = .87, BF_{10} = 0.10) or sex (r = -.12, p = .11, BF_{10} = 0.35), but it had a very weak association with education (r = .18, p = .02, BF_{10} = 1.36). In the statistical analyses, we considered duration of music training in two ways: as a continuous 7-point variable (as measured by the Gold-MSI, see below), and with group comparisons between highly trained participants and those with no training, which is the norm in this line of research (for a review, Schellenberg, 2020). Participants with 6 or more years of instrumental training were considered to be highly trained (n = 30), as in previous research (Zhang et al., 2020).

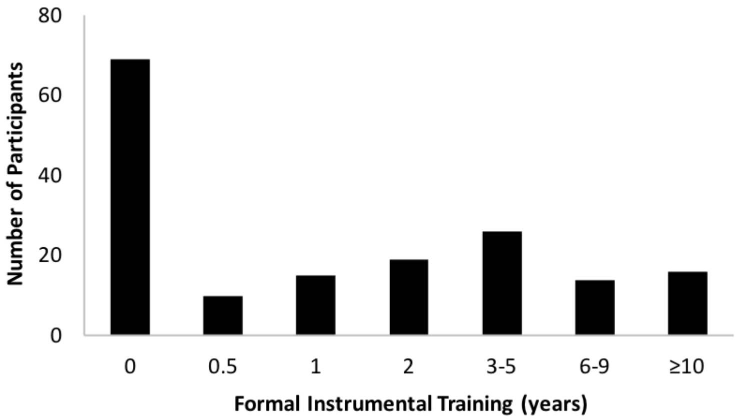

Figure 2.1. Distribution of formal instrumental training across participants.

Power analysis (with G*Power 3.1; Faul et al., 2009) indicated that for our main analyses, a sample of at least 134 participants was required to be 95% certain of detecting partial associations of r = .30 or larger between each predictor variable and emotion recognition accuracy, using multiple-regression models that included three predictors (music training, music perception abilities, and digit span).

2.2.2. Materials

2.2.2.1. Self-reported Musical Abilities

The Gold-MSI includes 38 items that cover a wide variety of music skills, expertise, and behaviors (Müllensiefen et al., 2014). It is suited for measuring individual differences among performing musicians as well as among members of the general population who vary in musical skills and interest in music. Scale items are grouped into five subscales, each of them corresponding to a different facet of musicality: active engagement (9 items; e.g., *I spend a lot of my free time doing music-related activities*), perceptual abilities (9 items, e.g., *I can tell when people sing or play out of tune*), music training (7 items, e.g., *I have had formal training in music theory for __ years*), singing abilities (7 items, e.g., *I am able to hit the right notes when I sing along with a recording*), and emotion (6 items, e.g., *I am able to talk about the emotions that a piece of music evokes for me*). For the first 31 items, participants indicate their level of agreement with each statement using a seven-point Likert scale (from 1 = *completely disagree* to 7 = *completely agree*). For the remaining items, participants use ordinal scales with seven response alternatives (e.g., *I can play [number from 0 to '6 or more'] instruments)*. Thus, for each participant, each original item is scored with an integer that ranges from 1 to 7.

The Gold-MSI and the Portuguese translation have good psychometric properties (Müllensiefen et al., 2014; Lima et al., 2018). Construct validity has been documented with associations between index scores and performance-based music perception tasks (i.e., beat alignment and melody memory, Müllensiefen et al., 2014; discrimination of pitch and duration, Dawson et al., 2017).

2.2.2.2. Performance-based Auditory and Musical Abilities

Four tasks were used to measure musical beat perception, melodic memory, pitch discrimination, and duration discrimination. The musical beat and melodic memory tasks were optimised versions of the ones used by Müllensiefen et al. (2014). For the *beat alignment* test, stimuli were 17 short excerpts of music (10-16 s), which included a beep track similar to a metronome. The beep track coincided with the implied beat of the music excerpt on four trials. On the other 13, the beep was phase shifted by 10% or 17.5%, or changed in tempo by 2%. On each trial, participants indicated whether the beat track was *on* or *off* the beat, as in the Beat Alignment Test (Iversen & Patel, 2008). The order of trials was randomized across participants.

For the *melodic memory* task (Harrison et al., 2016), participants listened to 13 pairs of short tunes (10-17 notes) and determined whether each pair was the *same* or *different*. The second tune was always transposed by 1 or 7 semitones. Thus, the task required listeners to determine whether both melodies had the same structure of consecutive musical intervals. Five pairs had a *different* structure, in which 1-3 notes were changed (as in Bartlett & Dowling, 1980; Cuddy & Lyons, 1981) to alter the contour and intervals, or maintain the contour but change the intervals. Both the musical beat and melodic memory tasks were implemented in PsychoPy

Experiment Builder v1.85.4 (http://www.psychopy.org/) by Estela Puig-Waldmüller and Bruno Gringras (University of Vienna), with Portuguese instructions. Each task took approximately 7 min to complete.

For the pitch and duration tasks, discrimination thresholds were obtained from a two-down-one-up adaptive staircase procedure, which tracked good but not perfect performance (70.7% correct) on the psychometric function (Soranzo & Grassi, 2014). For pitch discrimination, participants were presented with trials consisting of three consecutive 250 ms pure tones: two of them had the same frequency (always 1000 Hz) and one was higher. The difference was 100 Hz at the beginning, but subsequently varied from 2 to 256 Hz based on the listener's performance. Correct identification of the higher tone led to progressively smaller pitch differences until participants stopped responding correctly, whereas incorrect responses led to progressively larger differences until they responded correctly. For duration discrimination, listeners heard three pure tones on each trial, and judged which was the longest. Two of the tones were always 250 ms and one was longer by 100 ms at the beginning, but subsequently varied between 8 and 256 ms. For both tasks, the procedure ended after 12 reversals (i.e., changes in the direction of the stimulus difference). Thresholds were calculated by averaging the values of the last eight reversals. Lower values indicated better performance. The PSYCHOACOUSTICS toolbox (Soranzo & Grassi, 2014) running on MATLAB (R2016b, version 9.1.0) was used for both tasks, and each of them took approximately 5 min to complete, although duration varied depending on performance.

2.2.2.3. Emotion Recognition

Participants completed three emotion recognition tasks that were identical except for the stimuli. Two were auditory, with emotions conveyed through nonverbal vocalizations or speech prosody. The third was visual (facial expressions). Each task had 84 trials, with 12 different stimuli representing each of seven emotions (anger, disgust, fear, happiness, pleasure, sadness, and neutral). The stimuli were taken from previously validated corpora (speech prosody, Castro & Lima, 2010; nonverbal vocalizations, Lima et al., 2013; facial expressions, Karolinska Directed Emotional Faces database, Goeleven et al., 2008) and have been used frequently (e.g., Eisenbarth & Alpers, 2011; Lima & Castro, 2011; Lima et al., 2016a; Lima et al., 2013; Strachan et al., 2019).

Speech prosody stimuli were short sentences (M = 1472 ms, SD = 247) with emotionally neutral semantic content (e.g., "O quadro está na parede", *The painting is on the wall*), produced by two female speakers to communicate emotions with prosodic cues alone (i.e., variations in pitch, loudness, timing, and voice quality). Nonverbal vocalizations consisted of brief vocal sounds (*M* = 1013 ms, *SD* = 286) without verbal content, such as laughs, screams, or sobs, as produced by two female and two male speakers. Finally, facial expressions consisted of color photographs of male and female actors with no beards, moustaches, earrings, eyeglasses, or visible make-up. Each photograph was presented for 2 s. The three tasks were similarly difficult. Based on validation data from the different corpora, average recognition accuracy was 75.6% for speech prosody, 80.7% for nonverbal vocalizations, and 79.4% for facial expressions.

Participants made an eight-alternative forced-choice judgment for each stimulus in each task, selecting the emotion that was being expressed from a list that included *neutrality, anger, disgust, fear, happiness, pleasure, sadness,* and *none of the above.* Each of the three tasks started with four practice trials. The 84 experimental trials that followed were randomized separately for each participant. Each stimulus was presented once and no feedback was provided. The tasks were implemented in E-Prime 2.0 Professional (Version 2.0.10.356), and each took approximately 10 min to complete.

2.2.2.4. General Cognitive Ability

To index domain-general cognitive abilities, participants completed the forward and backward portions of the Digit Span subtest from the Wechsler Adult Intelligence Scale III (WAIS-III; Wechsler, 2008). A total score was the sum of the forward and backward raw scores.

2.2.3. Procedure

Participants were tested individually in a quiet room at the Speech Laboratory (Department of Psychology, University of Porto) or at LAPSO (Social and Organizational Psychology Lab, ISCTE-IUL). They completed a background questionnaire that asked for demographic information, and then the remaining questionnaires, the experimental tasks, and the digit span test. The order of the tasks was randomized across participants, and the testing session lasted about 1.5 hours. Short breaks were allowed between tasks. The auditory stimuli were presented via high-quality headphones (Sennheiser HD 280 Professional), with the volume adjusted to a comfortable level for each participant.

The same participants also completed a task that required them to compare the emotional features of pairs of musical excerpts (MacGregor & Müllensiefen, 2019), and a series of questionnaires that indexed emotion- and health-related variables. These results will be reported in a separate publication.

Some data were missing for some tasks: beat perception (*n* = 11), melodic memory (*n* = 17), pitch discrimination (*n* = 3), duration discrimination (*n* = 1), emotional prosody (*n* = 4), vocalizations (*n* = 2), faces (*n* = 5), and digit span (*n* = 1). Thus, the sample size varied slightly in the statistical analyses depending on which variables were involved.

2.2.4. Data Preparation and Analysis

Because we had four performance-based music perception tasks (musical beat perception, melodic memory, pitch and duration discrimination), we asked whether an aggregate variable could be formed and used as an index of musical ability to reduce collinearity and the contribution of measure-specific error variance. A principal component analysis (varimax rotation) revealed that a two-factor solution accounted for 73% of the variance in the original data. Three of the tasks loaded highly on the first component (beat perception, pitch discrimination, duration discrimination, *r*s = -.76, .79, and .81, respectively), whereas melodic memory was almost perfectly correlated with the second component (*r* = .98). In the analyses that follow, we used the original *melodic memory* accuracy scores, and an aggregate *music perception* variable that represented the principal component extracted from the other three variables, which was almost perfectly correlated with the first component from the original analysis (*r* = .98). Lower scores on this measure indicate better performance.

Accuracy rates for emotion recognition tasks were arcsine square-root transformed and corrected for possible response biases using unbiased hit rates, or Hu (Wagner, 1993; for a discussion of biases in forced-choice tasks, e.g., Isaacowitz et al., 2007). Hu values represent the difference between hits (number of times a given response category is correctly used) and false alarms (number of times a given response category is incorrectly used), divided by the total number of trials, such that they vary between 0 and 1. When all the stimuli from a category are correctly identified, Hu = 1; when no stimulus from category (e.g., happy) is correctly identified, Hu = 0. Hu scores were computed separately for each emotion, and then averaged for each task. Most analyses were conducted using these average scores because we had no predictions regarding specific emotions. For comparisons between trained and untrained participants, however, we also tested for the possibility of emotion-specific effects, in order to ensure that associations with training were not driven by a single emotion or a small subset of emotions, as they have been in previous research (Pinheiro et al., 2015; Thompson et al., 2004).

The data were statistically evaluated based on standard frequentist *and* Bayesian approaches (e.g., Jarosz & Wiley, 2014). In each analysis, a Bayes Factor (BF_{10}) statistic was estimated, which considers the likelihood of the observed data given the alternative and null hypotheses. These analyses were conducted on JASP Version 0.9.2 (JASP Team, 2018), using default priors (Rouder et al., 2012; Wagenmakers et al., 2016, 2018a, 2018b). BF_{10} values were interpreted following Jeffreys' guidelines (Jarosz & Wiley, 2014; Jeffreys, 1961), with values between 1 and 3 corresponding to weak/anecdotal evidence for the alternative hypothesis, values between 3 and 10 corresponding to substantial evidence, and values between 10 and 30, 30 and 100, and over 100 corresponding to strong, very strong, and decisive evidence, respectively. A $BF_{10} < 1$ provided evidence in favor of the null hypothesis ($BF_{10} < 0.33$ indicated substantial evidence, $BF_{10} < 0.10$ indicated strong evidence).

2.3. Results

2.3.1. Formal Music Training

Table 2.1 shows summary statistics for the full sample, for highly trained individuals only (*n* = 30), and for participants with no training (*n* = 69). Table 2.2 provides correlations between duration of music training and the other variables using the full sample. As in previous studies, music training was associated robustly with enhanced musical abilities on both self-report and performance-based tasks. Associations with general cognitive abilities were evident but weak.

Table 2.1. Descriptive Statistics for the Full Sample, and Separately for Highly Musically Trained and Untrained Participants

Task	Full sample (*N* = 169) Mean (*SD*)	Untrained (*n* = 69) Mean (*SD*)	Highly Trained (*n* = 30) Mean (*SD*)	*p*-value (BF_{10})
Digit Span (WAIS III; total)	15.11 (3.67)	14.58 (4.20)	16.69 (3.13)	.02 (2.94)
Gold-MSI (Likert scale, 1-7)				
Music Training	3.14 (1.68)	1.72 (0.71)	5.66 (0.77)	< .001 (> 100)
Perceptual Abilities	5.23 (0.94)	4.88 (0.95)	6.06 (0.63)	< .001 (> 100)
Active Engagement	4.19 (1.10)	3.87 (1.10)	4.86 (1.05)	< .001 (> 100)
Singing Abilities	4.23 (1.13)	3.85 (1.04)	5.14 (0.88)	< .001 (> 100)
Emotions	5.71 (0.77)	5.57 (0.86)	5.98 (0.60)	.02 (2.38)
Music Perception Tasks				
Aggregate Music Perception	0.00 (1.00)	0.31 (0.97)	-0.79 (0.75)	< .001 (> 100)
Melodic Memory (% correct)	63.51 (14.23)	59.10 (14.82)	73.08 (15.17)	< .001 (> 100)
Emotion recognition (average Hu scores)				
Prosody	.63 (.17)	.61 (.17)	.69 (.17)	.02 (2.70)
Vocalizations	.78 (.11)	.76 (.13)	.81 (.10)	.02 (2.65)
Faces	.70 (.10)	.69 (.12)	.70 (.09)	.93 (0.15)

Note. For the Gold-MSI and music perception tasks, *p* values correspond to the statistic of independent samples *t*-tests (two-tailed). For the emotion recognition tasks, *p* values correspond to the main effect of group in mixed-design ANOVAs, including music training as between-subject factor and emotion as repeated-measures factor.

As expected, duration of music training was correlated positively with average emotion recognition scores across the full sample, both for speech prosody and for nonverbal vocalizations (see Table 2.2). The effect was small (r = .21 in both cases), but Bayesian analyses indicated that the evidence was substantial. By contrast, for facial expressions, there was substantial evidence for a *null* effect. When digit span was held constant, associations between duration of training and emotion recognition remained significant for nonverbal vocalizations (partial r = .22, p = .01, BF_{10} = 9.45), and at marginal levels for speech prosody (partial r = .15, p = .06, BF_{10} = 1.03).

Table 2.2. Pairwise Correlations Between Duration of Music Training and Other Variables

Variable	r	p-value	BF_{10}
Digit Span (total)	.18	.02	1.60
Gold-MSI: Music Training	.89	< .001	> 100
Gold-MSI: Perceptual Abilities	.42	< .001	> 100
Gold-MSI: Active Engagement	.32	< .001	> 100
Gold-MSI: Singing Abilities	.44	< .001	> 100
Gold-MSI: Emotions	.18	.02	1.33
Aggregate Music Perception	-.39	< .001	> 100
Melodic Memory	.34	< .001	> 100
Emotion Recognition: Prosody (average)	.21	.01	3.71
Emotion Recognition: Vocalizations (average)	.21	.01	4.25
Emotion Recognition: Faces (average)	.10	.18	0.24

We then conducted group comparisons between highly trained participants and those without any training. Mixed-design Analyses of Variance (ANOVAs) were conducted for each task, with the different emotions as a repeated measure, and music training as a between-subjects factor. Greenhouse-Geisser corrections were applied when necessary (Mauchly's sphericity test). For speech prosody, we found a significant advantage for highly trained participants, $F(1, 95) = 5.80$, p = .02, η^2 = .06, although Bayesian statistics suggested that the evidence was weak, BF_{10} = 2.70. A main effect of emotion category confirmed that some emotions were more difficult to recognize than others, $F(4.98, 472.73) = 26.42$, $p < .001$, η_p^2 = .22, $BF_{10} > 100$, but there was no interaction between music training and emotion, p = .25, BF_{10} = .05. For nonverbal vocalizations, an advantage for trained participants was again observed, $F(1, 96) = 6.11$, p = .02, η^2 = .06, BF_{10} = 2.65. The main effect of emotion was significant, $F(4.30, 412.82) = 10.26$, p = .001, η_p^2 = .10, $BF_{10} > 100$, as was the interaction between music training and emotion, $F(4.30, 412.82) = 4.11$, $p = .002$, $\eta_p^2 = .04$, $BF_{10} = 37.32$. Follow-up analyses showed that trained participants were numerically better than their untrained counterparts for all emotions except anger (average Hu scores = .76 and .78 for trained and untrained participants, respectively, $p = .37$). Finally, for facial expressions, there was substantial evidence for a *null* effect of music training, $p = .93$, $BF_{10} = .15$, a main effect of emotion, $F(4.57, 439.29) = 59.83$, $p < .001$, $\eta_p^2 = .39$, $BF_{10} > 100$, but no interaction between training and emotion, $p = .41$, $BF_{10} = .03$.

When digit span was held constant, the advantage for highly trained participants remained significant for nonverbal vocalizations, $F(1, 94) = 6.15$, $p = .01$, $\eta_p^2 = .06$, $BF_{10} = 3.06$, as did the main effect of emotion, $p = .17$, $BF_{10} > 100$, and the interaction between training and emotion, $F(4.35, 409.23) = 2.76$, $p = .02$, $\eta_p^2 = .03$, $BF_{10} = 35.04$. For speech prosody, however, the main effect of emotion remained evident, $F(4.92, 457.55) = 4.46$, $p < .001$, $\eta_p^2 = .05$, $BF_{10} > 100$, but the advantage for trained participants disappeared, $F(1, 93) = 2.31$, $p = .13$, $BF_{10} = 0.60$, and there was no interaction between training and emotion, $p = .23$, $BF_{10} = .08$.

In short, we found evidence for an association between music training and the recognition of emotion in voices but not faces. The effect was small, however, and in the case of prosody it was partly related to individual differences in digit span.

2.3.2. Self-reported Musical Abilities

We then tested for associations between emotion recognition and facets of musical abilities other than music training, as assessed by the subscales from the Gold-MSI. Zero-order correlations are provided in the upper part of Table 2.3. As predicted, we found decisive evidence that higher music perception abilities correlated with higher emotion recognition accuracy. These associations were observed for prosody and nonverbal vocalizations, but not for facial expressions. Exploratory analyses also revealed an unpredicted association between singing abilities and emotion recognition performance, but only for speech prosody.

An important question was whether the association between music perception and vocal emotion recognition would remain evident when music training and general cognitive abilities were held constant. Using multiple regression, we modelled average accuracy on the speech prosody task as a function of music perception abilities, duration of music training, and digit span. The model explained 14.6% of the variance, $R = .38$, $F(3,162) = 9.23$, $p < .001$, $BF_{10} > 100$. Independent contributions to the model were evident for music perception, partial $r = .18$, $p = .02$, $BF_{10} = 2.92$, and digit span, partial $r = .23$, $p = .003$, $BF_{10} = 12.54$, but not for music training, p = .38, BF_{10} = 0.33. A similar regression analysis was conducted for nonverbal vocalizations. The three-predictor model explained 14.3% of the variance, R = .38, $F(3,163)$ = 9.06, $p < .001$, $BF_{10} > 100$. Music perception abilities made a decisive independent contribution to the model, partial r = .32, $p < .001$, $BF_{10} > 100$, digit span contributed anecdotally, partial r = -.16, p = .04, BF_{10} = 1.86, but music training was irrelevant, p = .16; BF_{10} = 1.76. Associations between self-reported music perception abilities and vocal emotion recognition are illustrated in the upper part of Figure 2.

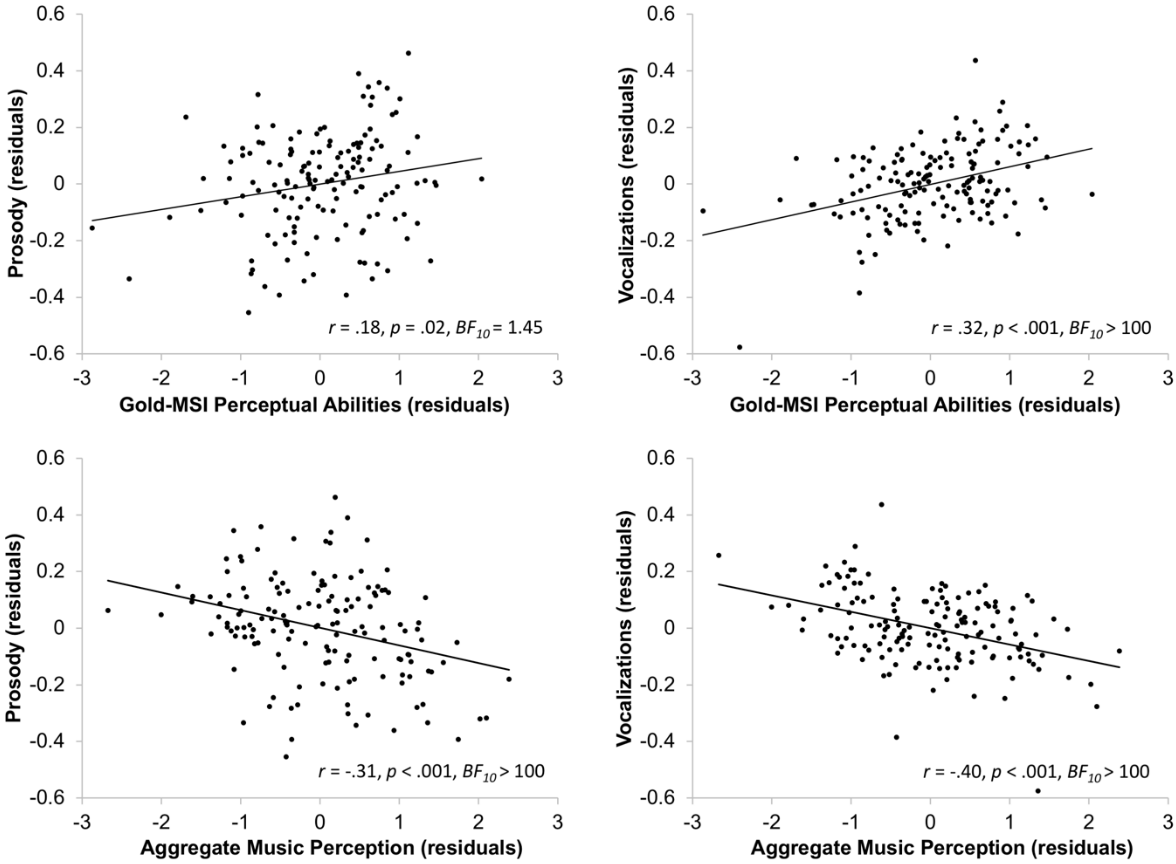

Figure 2.2. Partial regression plots illustrating the relationship between music perception abilities (Gold-MSI Perceptual Abilities and Aggregate Music Perception) and vocal emotion recognition (prosody and vocalizations), after removing the effects of music training and digit span. Lower scores in Aggregate Music Perception indicate better performance.

We also confirmed that self-reported music perception abilities predicted unique variance in vocal emotion recognition even when age, sex, and education were added to the regression models (in addition to music training and digit span), ps ≤ .02, all $BF_{10} > 3.17$.

Table 2.3. Correlations Between Emotion Recognition and Musical Abilities as Measured with Gold-MSI Subscales and Objective Music Perception Tasks.

	Prosody		Vocalizations		Faces	
Task	*r*	BF_{10}	*r*	BF_{10}	*r*	BF_{10}
Gold-MSI						
Perceptual abilities	.32**	>100	.34**	>100	.15	0.63
Active engagement	.20	2.73	.21	4.25	.11	0.24
Singing abilities	.30*	>100	.22	6.11	.16	0.72
Emotions	.14	0.48	.18	1.27	.18	1.33
Music Perception Tasks						
Aggregate Music Perception	-.39**	>100	-.42**	>100	-.18	1.03
Melodic memory	.12	0.28	.12	0.31	.22	4.01

Note. $^*p < .05$, $^{**}p < .001$ (Holm Bonferroni-corrected).

2.3.3. Performance-based Musical Abilities

In the next set of analyses, we asked whether similar findings could be observed for objective measures of music perception abilities. As shown in the lower part of Table 2.3, no associations were found for melodic memory, but we found decisive evidence for a positive association in the case of the aggregate measure. Participants with higher music perception abilities also had improved emotion recognition for prosody and nonverbal vocalizations, but not for facial expressions.

Multiple-regression models showed that these associations remained evident when music training and digit span were held constant. For speech prosody, a model with three predictor variables (aggregate measure of music perception, duration of music training and digit span) accounted for 18.8% of the variance, R = .43, F(3,148) = 11.44, p < .001, BF_{10} > 100. Independent contributions were made by the aggregate measure of music perception, partial r = -.31, p < .001, BF_{10} > 100, and digit span, partial r = .21, p = .01, BF_{10} = 5.37, but there was no contribution of music training, p = .93; BF_{10} = 0.22. A similar model for nonverbal vocalizations accounted for 20.5% of the variance R = .45, F(3,149) = 12.79, p < .001, BF_{10} > 100. Independent contributions were again evident for the aggregate measure of music perception, partial r = -.40, p < .001, BF_{10} > 100, and digit span, partial r = -.18 p = .03, BF_{10} = 2.28, but not for music training, p = .31, BF_{10} = 0.34. Associations between objective music perception abilities and vocal emotion recognition are illustrated in the lower part of Figure 2. The aggregate measure of music perception abilities predicted unique variance in vocal emotion recognition even when age, sex, and education were also included in the regression models, *p*s < .001, all BF_{10} > 100.

2.3.4. Nonmusicians with Good Musical Abilities vs. Highly Trained Participants

The previous analyses established that individuals with better music perception abilities are also better at recognizing vocal emotions, regardless of music training. An interesting question is whether untrained participants with good musical abilities show emotion recognition performance comparable to that of trained musicians. To address this question, we divided untrained participants into high and low musical abilities groups, based on median-splits of the music perception measures. Separate analyses were conducted for self-reported music perception scores and the aggregate measure of music perception. We then compared those with high musical abilities with trained musicians[1]. For speech prosody, there was no advantage for trained participants: self-reports, $t(63) = -1.48$, $p = .14$, $BF_{10} = 0.64$; performance-based skills, $t(58) = -1.98$, $p = .05$, $BF_{10} = 1.30$. Similarly, for nonverbal vocalizations, highly trained participants did not differ from untrained ones with good musical abilities: self-reports, $t(63) = -1.54$, $p = .69$, $BF_{10} = 0.65$; performance-based skills, $t(58) = -1.39$, $p = .17$, $BF_{10} = 0.59$. In short, musician-like enhancements in vocal emotion recognition were evident in participants without any formal music training, provided they had good musical abilities.

2.3.5. Mediation Analyses

A final analysis determined whether the association between music training and emotion recognition was mediated by music perception skills, which are enhanced in trained individuals. These analyses were conducted using the PROCESS macro for SPSS (Version 3.3; Hayes, 2017), with statistical inferences based on percentile bootstrap 95% confidence intervals (CIs) with 20,000 samples. Total, direct, and indirect (mediated) effects were estimated, and were considered significant when the CIs did not include 0.

The mediation models are depicted in Figure 3. For speech prosody, the indirect effect of music training on emotion recognition scores – through self-reported music perception skills – was significant. The direct effect was not, however, indicating that there was no association between training and emotion recognition performance when music perception skills were held constant. Identical results emerged when the objective music perception measure (aggregate measure) was substituted for the self-reported one, as well as in similar analyses for nonverbal

[1] Nonmusicians with good musical abilities and trained musicians were generally similar in digit span and sample size. Nonmusicians with good musical abilities: based on self-reports, $n = 36$, digit span $M = 15.19$; based on performance-based skills, $n = 32$, digit span $M = 15.09$. Trained musicians: based on self-reports, $n = 30$, digit span $M = 16.69$; based on performance-based skills, $n = 29$, $M = 16.75$.

vocalizations. In short, duration of music training was positively associated with enhanced emotion recognition simply because trained individuals had enhanced music perception skills.

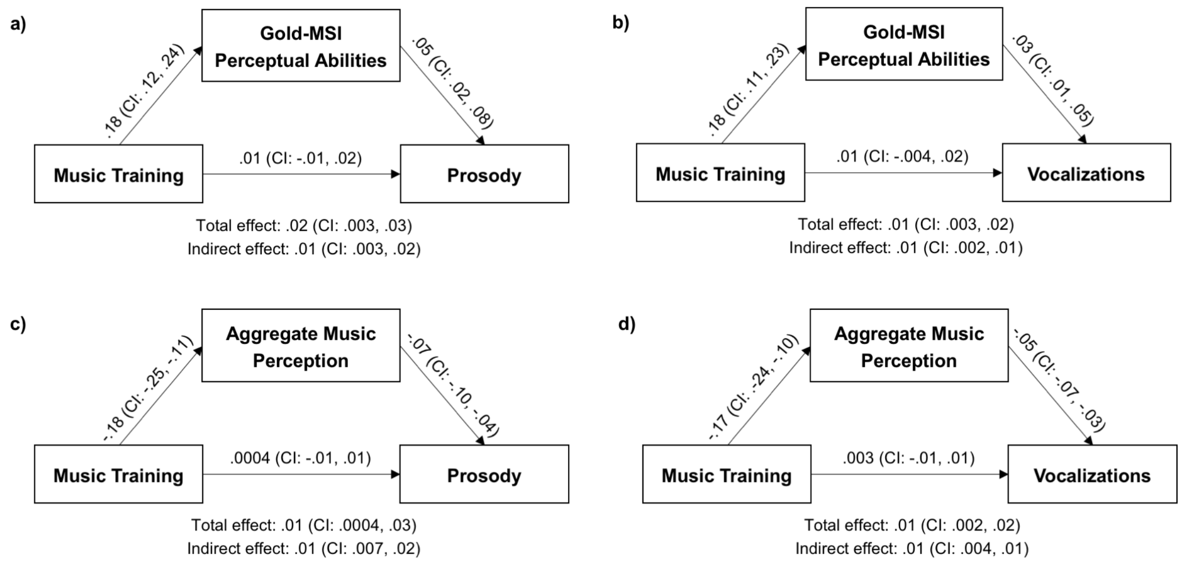

Figure 2.3. Models depicting the mediation effect of music perception abilities (Gold-MSI Perceptual Abilities and Aggregate Music Perception) on the association between music training and vocal emotion recognition (prosody and vocalizations). Inference was based on percentile bootstrap 95% confidence intervals (CIs) with 20.000 samples. Lower scores in Aggregate Music Perception indicate better performance.

2.4. Discussion

The present study examined the association between musical expertise and the ability to recognize emotions in vocal and facial expressions. We examined associations with formal music training and, crucially, we investigated whether, in the absence of training, having good musical abilities related to enhancements in emotion recognition similar to the ones seen in musicians. The analyses had four main findings. First, music training was associated with better emotion recognition in speech prosody and nonverbal vocalizations. The advantage was small, though, and restricted to the auditory domain (i.e., not observed for facial emotion recognition). Second, we found a robust association between music perception skills and enhanced vocal emotion recognition, which remained significant even when music training and general cognitive abilities were held constant. Importantly, untrained participants with good musical abilities showed vocal emotion recognition performance comparable to that of trained musicians. Third, self-reported singing abilities was associated positively with emotional prosody recognition. Fourth, mediation analyses showed that the effect of music training on vocal emotion recognition was fully mediated by music perception skills.

In previous studies, an advantage for musicians in emotional prosody recognition has been reported in some instances (Lima & Castro, 2011; Thompson et al., 2004), but not in others (Mualem & Lavidor, 2015; Park et al., 2015; Trimmer & Cuddy, 2008). The present study was the first to examine whether musicianship predicts the recognition of emotions in other types of vocal expressions. Our results corroborated the association with speech prosody and extended it to nonverbal vocalizations. The advantage for vocalizations was consistent with previous evidence showing a more efficient subcortical encoding of crying sounds in musicians compared to nonmusicians (Strait et al., 2009). In short, the effect of music training can be seen for vocal emotional stimuli with or without linguistic information, which suggests that it might stem from a general benefit in decoding vocal emotional cues, because emotional speech and nonverbal vocalizations differ in their production and perceptual mechanisms (Scott et al., 2010). For instance, electrophysiological evidence indicates that vocalizations and emotional prosody are differentiated rapidly, with preferential processing of vocalizations at early stages of auditory processing and allocation of attention (N1-P2 components; Pell et al., 2015). The failure of some previous studies to replicate the musicians' advantage in emotion recognition could be because the association appears to be small and relatively weak, as suggested by our Bayesian analyses. In other words, a relatively large sample of highly trained participants might be required for such an association to emerge. In previous studies with null findings, the samples included less than 15 musicians (Park et al., 2015; Pinheiro et al., 2015), or participants with only a modicum of training.

We also found that, in the case of speech prosody (but not in the case of vocalizations), the effect of music training became non-significant after accounting for individual differences in digit span. This finding implies that the association could be a consequence of domain-general cognitive abilities. In an earlier study, however, Lima and Castro (2011) documented that associations between musical expertise and prosody were independent of general abilities. This discrepancy might stem from differences in samples, or from the particular way domain-general abilities are measured. Our digit-span task measured auditory-perceptual processes, which could, arguably, be a consequence of the training itself rather than a proper confounding variable. By contrast, Lima and Castro (2011) had several domain-general cognitive tasks, including purely nonverbal ones such as Raven's Advanced Progressive Matrices. The precise role of distinct domain-general processes could be addressed in future studies.

A novel but null finding of the present study was that music training had no association with emotion recognition in the visual domain. Thus, musicians' advantage in emotion recognition may be restricted to the auditory domain. Our decision to include a facial emotion recognition task was motivated by evidence of domain-general socio-emotional processing difficulties in congenital amusia (Lima et al., 2016a). There is also evidence that musicians show stronger responses to emotional prosody in brain regions involved in modality-independent inferences about mental states, including the medial prefrontal and anterior cingulate cortices (Park et al., 2015). Moreover, socio-emotional stimuli in everyday life are typically multimodal, such that individual differences in basic auditory skills could have cascading effects that extend to higher-order aspects of socio-emotional cognition. Perhaps the enhancements associated with good musical abilities are relatively small, and thus incapable of being observable across domains. In the case of congenital amusia, affected individuals have severe pitch deficits that likely to influence early stages of socio-emotional development. Our null results for music training and visual stimuli are consistent with recent meta-analyses that raise doubts about far transfer in general, and as a consequence of music training in particular (Sala & Gobet, 2017a, 2017b). Indeed, in some instances, there is no association between music training and performance on non-musical *auditory* tasks such as perceiving speech in noise (Boebinger et al., 2015; Madsen et al., 2019).

By assessing basic auditory and music perception skills in addition to music training, we were able to find robust evidence that being a musician is not a necessary condition for music-related advantages in vocal emotion recognition. Converging data from self-report and performance-based measures indicated, moreover, that auditory and musical skills are broadly associated with enhanced emotional processing of speech prosody and nonverbal vocalizations, even after accounting for training. These findings suggest that neurocognitive pathways for music and vocal emotions overlap, and that such overlap stems from aspects of musical expertise other than formal training. Crucially, they establish a role for factors other than formal training in associations between musical and nonmusical abilities, specifically musical abilities that are driven by innate predispositions and/or informal engagement with music.

Our findings also align well with recent evidence of associations between music and speech and language processing. For example, Swaminathan and Schellenberg (2017, 2020) found that for adults and children, rhythm perception abilities were associated positively with phoneme discrimination in a foreign language, even after controlling for music training and domain-general cognitive abilities. In other words, music perception skills (i.e., rhythm in this instance) were a better predictor of speech perception than music training.

Mankel and Bidelman (2018) examined neuroelectric brain responses to clear and noise-degraded speech sounds in musical untrained participants. At a neuronal level, participants with higher music perception skills had more tightly linked frequency-following responses to speech, and more faithful representations of speech in noise. Although the authors proposed that music training provides an additional boost, on top of pre-existing skills, to the neural processing of speech, they had no evidence for this assertion, and we did not find evidence for such a boost in the current study. Rather, our highly adept nonmusicians showed vocal emotion recognition performance that was on par with highly trained musicians. Perhaps the level of analysis plays a role. Mankel and Bidelman (2018) emphasized neural measures, whereas our evidence was behavioral. In fact, Mankel and Bidelman found different results for neural and behavioral measures: although neural measures were sensitive to fine differences in musical skills, a behavioral measure was not. In short, advantages related to musical abilities (in the absence of training) are not discernible from those attributed to training at a behavioral level.

Although we documented an important role of predispositions and informal experience in the association between musical abilities and vocal emotion recognition, we do not doubt that music training can produce experience-dependent effects. Carefully designed longitudinal studies with random assignment provide evidence for such effects across a range of tasks, at behavioral and neural levels (Bangert & Altenmüller, 2003; Chobert et al., 2012; Francois et al., 2012; Frey et al., 2019; Moreno et al., 2009, 2011; Schellenberg, 2004), yet more research is crucial to clarify the robustness and scope of such effects. Moreover, group differences that are evident in cross-sectional studies have often been causally attributed to training (Schellenberg, 2020), yet the current findings confirm that similar advantages can be seen in individuals without any training. By equating musical expertise with music training, neuroscientists and psychologists are exhibiting a limited perspective of the genetic and environmental factors that shape musical abilities, and of the richness and diversity of musical behaviors and experience. A complete understanding of musicality and its role in cognition requires a complex and multifaceted exploration of musical skills.

In exploratory analyses, we found that self-reports of singing abilities were associated positively with recognizing emotions in speech prosody. This finding implies that other facets of musical expertise are involved in associations with vocal emotions. It is also consistent with well-documented behavioral and neural links between production, imagery, and perceptual mechanisms that are involved in voice processing (Correia et al., 2019; Lima et al., 2015; Lima et al., 2016b; McGettigan et al., 2015; Pfordresher & Halpern, 2013; Warren et al., 2006). On the one hand, vocal production (such as singing) involves not only implementing movements, but also planning and anticipating outcomes (which might rely on imagery), and using auditory feedback (perceptual processes) to detect and correct errors. On the other hand, listening to sounds, namely vocal emotional sounds, recruits auditory areas in the temporal lobes as well as areas involved in motor planning and control. The involvement of the motor system is also correlated positively with enhanced vocal emotional processing (Correia et al., 2019; McGettigan et al., 2015), which suggests that more efficient activation of sound-related motor representations optimizes perceptual processes (for review see Lima et al., 2016b). It is therefore plausible that such tight production-perception links in voice processing account for the positive association between singing and speech prosody perception, a prediction that could be tested systematically in future studies. For example, singing abilities could be assessed not only via self-report but also with performance-based tasks (e.g., Pfordresher & Halpern, 2013).

Previous studies provided suggestive evidence that the primary locus for transfer effects from music training to vocal emotions is at a basic auditory-perceptual level of processing. Music training could lead to more efficient auditory-perceptual processing (Kraus & Chandrasekaran, 2010; Herholz & Zatorre, 2012), which in turn could facilitate vocal emotion recognition, because sensory processing is central to vocal communication (Schirmer & Kotz, 2006). Our mediation analysis provided results consistent with this view, in the sense that no other component of musical expertise played an important role. Indeed, the effect of training on vocal emotion recognition was accounted for entirely by advantages in music perception skills. This finding can be interpreted within the framework of the OPERA hypothesis, which describes transfer effects from music training to the encoding of speech (Patel, 2011, 2014). Because the brain networks that process acoustic features are used in music and speech, musicians may exhibit speech processing benefits because their training includes several features that could modulate these networks (precision, emotion, repetition, and attention). It is noteworthy that the association between auditory-perceptual skills and emotion processing did not extend to visual domain, which implies that the overlap between musical skill and emotion recognition does not extend to higher-order levels of processing. Future studies using techniques such as EEG or fMRI could be useful to address these questions more directly, because they can tell us *when* cross-domain interactions occur (early vs. later stages of processing) and if they occur primarily in auditory areas or, rather, extend to regions involved in supramodal socio-emotional processing.

To conclude, the present study represents the first demonstration that better music perception skills are associated with enhancements in vocal emotion recognition, even in the absence of any formal music training. Untrained individuals who are naturally musical can be as good as highly trained musicians at recognizing emotions in speech prosody and nonverbal vocalizations. Our findings do not rule out the possibility that music training induces experience-dependent effects, but they affirm an important role of pre-existing factors in associations between music and nonmusical domains that have been neglected in the literature. Collectively, the results reported here emphasize the need to interpret cross-sectional music training effects with caution. They also confirm that there are multiple facets to musical expertise beyond formal training, which future research could examine in greater detail.

References

Bangert, M., & Altenmüller, E. O. (2003). Mapping perception to action in piano practice: A longitudinal DC-EEG study. *BMC Neuroscience, 4*(26). https://doi.org/10.1186/1471-2202-4-26

Bartlett, J. C., & Dowling, W. J. (1980). Recognition of transposed melodies: A key-distance effect in developmental perspective. Jo*urnal of Experimental Psychology: Human Perception and Performance, 6*(3), 501-515. https://doi.org/10.1037/0096-1523.6.3.501

Bigand, E., & Poulin-Charronnat, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition*, *100*(1), 100-130. https://doi.org/10.1016/j.cognition.2005.11.007

Boebinger, D., Evans, S., Rosen, S., Lima, C. F., Manly, T., & Scott, S. K. (2015). Musicians and nonmusicians are equally adept at perceiving masked speech. *The Journal Of The Acoustical Society Of America*, *137*(1), 378-387. https://doi.org/10.1121/1.4904537

Brück, C., Kreifelts, B., & Wildgruber, D. (2011). Emotional voices in context: A neurobiological model of multimodal affective information processing. *Physics Of Life Reviews*, *8*(4), 383-403. https://doi.org/10.1016/j.plrev.2011.10.002

Castro, S. L., & Lima, C. F. (2010). Recognizing emotions in spoken language: A validated set of Portuguese sentences and pseudosentences for research on emotional prosody. *Behavior Research Methods*, *42*(1), 74-81. https://doi.org/10.3758/brm.42.1.74

Chobert, J., Francois, C., Velay, J. L., & Besson, M. (2012). Twelve months of active musical training in 8- to 10-year-old children enhances the preattentive processing of syllabic duration and voice onset time. *Cerebral Cortex*, *24*(4), 956-967. https://doi.org/10.1093/cercor/bhs377

Clark, C., Downey, L., & Warren, J. (2015). Brain disorders and the biological role of music. *Social Cognitive And Affective Neuroscience*, *10*(3), 444-452. https://doi.org/10.1093/scan/nsu079

Coffey, E. B. J., Chepesiuk, A. M. P., Herholz, S. C., Baillet, S., & Zatorre, R. J. (2017). Neural correlates of early sound encoding and their relationship to speech-in-noise perception. *Frontiers In Neuroscience, 11*. https://doi.org/10.3389/fnins.2017.00479

Correia, A. I., Branco, P., Martins, M., Reis, A. M., Martins, N., Castro, S. L., & Lima, C. F. (2019). Resting-state connectivity reveals a role for sensorimotor systems in vocal emotional processing in children. *NeuroImage*, *201*, 116052. https://doi.org/10.1016/j.neuroimage.2019.116052

Cuddy, L. L., & Lyons, H. I. (1981). Musical pattern recognition: A comparison of listening to and studying tonal structures and tonal ambiguities. *Psychomusicology: A Journal Of Research In Music Cognition*, *1*, 15-33. https://doi.org/10.1037/h0094283

Dawson, C., Aalto, D., Šimko, J., Vainio, M., & Tervaniemi, M. (2017). Musical sophistication and the effect of complexity on auditory discrimination in Finnish speakers. *Frontiers in Neuroscience, 11*. https://doi.org/10.3389/fnins.2017.00213

Degé, F., & Schwarzer, G. (2011). The effect of a music program on phonological awareness in preschoolers. *Frontiers In Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00124

Eisenbarth, H., & Alpers, G. W. (2011). Happy mouth and sad eyes: Scanning emotional facial expressions. *Emotion*, *11*(4), 860-865. https://doi.org/10.1037/a0022758

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149-1160. https://doi.org/10.3758/brm.41.4.1149

Francois, C., Chobert, J., Besson, M., & Schon, D. (2012). Music training for the development of speech segmentation. *Cerebral Cortex, 23*(9), 2038-2043. https://doi.org/10.1093/cercor/bhs180

Frey, A., François, C., Chobert, J., Velay, J. L., Habib, M., & Besson, M. (2019). Music training positively influences the preattentive perception of voice onset time in children with dyslexia: A Longitudinal study. *Brain Sciences*, *9*(4), 91. https://doi.org/10.3390/brainsci9040091

Goeleven, E., De Raedt, R., Leyman, L., & Verschuere, B. (2008). The Karolinska Directed Emotional Faces: A validation study. *Cognition & Emotion*, *22*(6), 1094-1118. https://doi.org/10.1080/02699930701626582

Good, A., Gordon, K. A., Papsin, B. C., Nespoli, G., Hopyan, T., Peretz, I., & Russo, F. A. (2017). Benefits of music training for perception of emotional speech prosody in deaf children with cochlear implants. *Ear And Hearing*, *38*(4), 455-464. https://doi.org/10.1097/aud.0000000000000402

Habibi, A., Cahn, B. R., Damasio, A., & Damasio, H. (2016). Neural correlates of accelerated auditory processing in children engaged in music training. *Developmental Cognitive Neuroscience, 21*, 1-14. https://doi.org/10.1016/j.dcn.2016.04.003

Harrison, P., Musil, J., & Müllensiefen, D. (2016). Modelling melodic discrimination tests: Descriptive and explanatory approaches. *Journal of New Music Research*, *45*(3), 265-280. https://doi.org/10.1080/09298215.2016.1197953

Hayes, A. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (2nd ed.). Guilford.

Herholz, S. C., & Zatorre, R. J. (2012). Musical training as a framework for brain plasticity: Behavior, function, and structure. *Neuron*, *76*(3), 486-502. https://doi.org/10.1016/j.neuron.2012.10.011

Honing, H. (2019). *The evolving animal orchestra: In search of what makes us musical*. MIT Press.

Iversen, J. R., & Patel, A. D. (2008). The beat alignment test (BAT): surveying beat processing abilities in the general population. *Proceedings of the 10th International Conference on Music Perception and Cognition,* 465-468.

Isaacowitz, D., Löckenhoff, C., Lane, R., Wright, R., Sechrest, L., Riedel, R., & Costa, P. (2007). Age differences in recognition of emotion in lexical stimuli and facial expressions. *Psychology And Aging*, *22*(1), 147-159. https://doi.org/10.1037/0882-7974.22.1.147

Jarosz, A., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting Bayes factors. *The Journal of Problem Solving, 7*(1), 2-9. https://doi.org/10.7771/1932-6246.1167

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford University Press.

Juslin, P. N., & Laukka, P. (2003). Communication of emotions in vocal expression and music performance: Different channels, same code?. *Psychological Bulletin*, *129*(5), 770-814. https://doi.org/10.1037/0033-2909.129.5.770

Koelsch, S. (2014). Brain correlates of music-evoked emotions. *Nature Reviews Neuroscience, 15,* 170-180. https://doi.org/10.1038/nrn3666

Koelsch, S. (2015). Music-evoked emotions: Principles, brain correlates, and implications for therapy. *Annals Of The New York Academy Of Sciences*, *1337*(1), 193-201. https://doi.org/10.1111/nyas.12684

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews Neuroscience*, *11*(8), 599-605. https://doi.org/10.1038/nrn2882

Krishnan, S., Lima, C. F., Evans, S., Chen, S., Guldner, S., Manly, T., & Scott, S. K. (2018). Beatboxers and guitarists engage sensorimotor fields when listening to the instruments they can play. *Cerebral Cortex, 28*(11), 4063-4079. https://doi.org/10.1093/cercor/bhy208.

Lima, C. F., Brancatisano, O., Fancourt, A., Müllensiefen, D., Scott, S. K., Warren, J. D., & Stewart, L. (2016a). Impaired socio-emotional processing in a developmental music disorder. *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep34911

Lima, C. F., & Castro, S. L. (2011). Speaking to the trained ear: Musical expertise enhances the recognition of emotions in speech prosody. *Emotion*, *11*(5), 1021-1031. https://doi.org/10.1037/a0024521

Lima, C. F., Castro, S. L., & Scott, S. K. (2013). When voices get emotional: A corpus of nonverbal vocalizations for research on emotion processing. *Behavior Research Methods, 45*(4), 1234-1245. https://doi.org/10.3758/s13428-013-0324-3

Lima, C. F., Correia, A. I., Müllensiefen, D., & Castro, S. L. (2018). Goldsmiths Musical Sophistication Index (Gold-MSI): Portuguese version and associations with socio-demographic factors, personality and music preferences. *Psychology of Music*. Advance online publication. https://doi.org/10.1177/0305735618801997

Lima, C. F., Krishnan, S., & Scott, S. K. (2016b). Roles of supplementary motor areas in auditory processing and auditory imagery. *Trends In Neurosciences*, *39*(8), 527-542. https://doi.org/10.1016/j.tins.2016.06.003

Lima, C. F., Lavan, N., Evans, S., Agnew, Z., Halpern, A. R., Shanmugalingam, P., Meekings, S., Boebinger, D., Ostarek, M., McGettigan, C., Warren, J. E., & Scott, S. K. (2015). Feel the noise: Relating individual differences in auditory imagery to the structure and function of sensorimotor systems. *Cerebral Cortex*, *25*(11), 4638-4650. https://doi.org/10.1093/cercor/bhv134

Madsen, S. M. K., Marschall, M., Dau, T., & Oxenham. A. J. (2019). Speech perception is similar for musicians and non-musicians across a wide range of conditions. *Scientific Reports, 9*(1), 10404. https://doi.org/10.1038/s41598-019-46728-1

McGettigan, C., Walsh, E., Jessop, R., Agnew, Z. K., Sauter, D. A., Warren, J. E., & Scott, S. K. (2015). Individual differences in laughter perception reveal roles for mentalizing and sensorimotor systems in the evaluation of emotional authenticity. *Cerebral Cortex, 25*(1)*,* 246-257. https://doi.org/10.1093/cercor/bht227

MacGregor, C., & Müllensiefen, D. (2019). The Musical Emotion Discrimination Task: A new measure for assessing the ability to discriminate emotions in music. *Frontiers In Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.01955

Mankel, K., & Bidelman, G. M. (2018). Inherent auditory skills rather than formal music training shape the neural encoding of speech. *Proceedings Of The National Academy Of Sciences USA, 115*(51), 13129-13134. https://doi.org/10.1073/pnas.1811793115

Marques, C., Moreno, S., Castro, S. L., & Besson, M. (2007). Musicians detect pitch violation in a foreign language better than nonmusicians: Behavioral and electrophysiological evidence. *Journal Of Cognitive Neuroscience*, *19*(9), 1453-1463. https://doi.org/10.1162/jocn.2007.19.9.1453

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425-1433. https://doi.org/10.1177/0956797611416999

Moreno, S., & Bidelman, G. M. (2014). Examining neural plasticity and cognitive benefit through the unique lens of musical training. *Hearing Research, 308*, 84-97. https://doi.org/10.1016/j.heares.2013.09.012

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: More evidence for brain plasticity. *Cerebral Cortex*, *19*(3), 712-723. https://doi.org/10.1093/cercor/bhn120

Moritz, C. E., Yampolsky, S., Papadelis, G., Thomson, J. M., & Wolf, M. (2012). Links between early rhythm skills, musical training, and phonological awareness. *Reading And Writing*, *26*(5), 739-769. https://doi.org/10.1007/s11145-012-9389-0

Mosing, M. A., Madison, G., Pedersen, N. L., Kuja-Halkola, R., & Ullén, F. (2014). Practice does not make perfect. *Psychological Science*, *25*(9), 1795-1803. https://doi.org/10.1177/0956797614541990

Mualem, O., & Lavidor, M. (2015). Music education intervention improves vocal emotion recognition. *International Journal Of Music Education*, *33*(4), 413-425. https://doi.org/10.1177/0255761415584292

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of nonmusicians: An index for assessing musical sophistication in the general population. *PLOS ONE, 9*(2), e89642. https://doi.org/10.1371/journal.pone.0089642

Park, M., Gutyrchik, E., Welker, L., Carl, P., Poppel, E., Zaytseva, Y., Meindl, T., Blautzik, J., Reiser, M., & Bao, Y. (2015). Sadness is unique: neural processing of emotions in speech prosody in musicians and nonmusicians. *Frontiers in Human Neuroscience, 8,* 1-8. https://doi.org/10.3389/fnhum.2014.01049

Patel, A. D. (2011). Why would musical training benefit the neural encoding of speech? The OPERA hypothesis, *8. Frontiers in Psychology, 2*. https://doi.org/10.3389/fpsyg.2011.00142

Patel, A. D. (2014). Can nonlinguistic musical training change the way the brain processes speech? The expanded OPERA hypothesis. *Hearing Research, 308*, 98-108. https://doi.org/10.1016/j.heares.2013.08.011

Pell, M. D., Rothermich, K., Liu, P., Paulmann, S., Sethi, S., & Rigoulot, S. (2015). Preferential decoding of emotion from human non-linguistic vocalizations versus speech prosody. *Biological Psychology*, *111*, 14-25. https://doi.org/10.1016/j.biopsycho.2015.08.008

Peretz, I., & Coltheart, M. (2003). Modularity of music processing. *Nature Neuroscience*, *6*(7), 688-691. https://doi.org/10.1038/nn1083

Pfordresher, P., & Halpern, A. R. (2013). Auditory imagery and the poor-pitch singer. *Psychonomic Bulletin & Review*, *20*(4), 747-753. https://doi.org/10.3758/s13423-013-0401-8

Pinheiro, A. P., Vasconcelos, M., Dias, M., Arrais, N., & Gonçalves, Ó. F. (2015). The music of language: An ERP investigation of the effects of musical training on emotional prosody processing. *Brain And Language, 140*, 24-34. https://doi.org/10.1016/j.bandl.2014.10.009

Roden, I., Grube, D., Bongard, S., & Kreutz, G. (2013). Does music training enhance working memory performance? Findings from a quasi-experimental longitudinal study. *Psychology Of Music, 42*(2), 284-298. https://doi.org/10.1177/0305735612471239

Rouder, J. N., Morey R. D., Speckman P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology, 56*(5), 356-374. https://doi.org/10.1016/j.jmp.2012.08.001

Sala, G., & Gobet, F. (2017a). Does far transfer exist? Negative evidence from chess, music, and working memory training. *Current Directions in Psychological Science, 26*(6), 515-520. https://doi.org/10.1177/0963721417712760

Sala, G., & Gobet, F. (2017b). When the music's over. Does music skill transfer to children's and young adolescents' cognitive and academic skills? A meta-analysis. *Educational Research Review, 20*, 55-67. https://doi.org/10.1016/j.edurev.2016.11.005

Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. *British Journal Of Psychology, 102*(3), 283-302. https://doi.org/10.1111/j.2044-8295.2010.02000.x

Schellenberg, E. G. (2019). Correlation = causation? Music training, psychology, and neuroscience. *Psychology Of Aesthetics, Creativity, And The Arts,* 1-6. https://doi.org/10.1037/aca0000263

Schellenberg, E. G., Corrigall, K., Dys, S., & Malti, T. (2015). Group music training and children's prosocial skills. *PLOS ONE, 10*(10), e0141449. https://doi.org/10.1371/journal.pone.0141449

Schirmer, A., & Kotz, S. A. (2006). Beyond the right hemisphere: brain mechanisms mediating vocal emotional processing. *Trends In Cognitive Sciences*, *10*(1), 24-30. https://doi.org/10.1016/j.tics.2005.11.009

Schön, D., Magne, C., & Besson, M. (2004). The music of speech: Music training facilitates pitch processing in both music and language. *Psychophysiology*, *41*(3), 341-349. https://doi.org/10.1111/1469-8986.00172.x

Scott, S. K., Sauter, D., & McGettigan, C. (2010). Brain mechanisms for processing perceived emotional vocalizations in humans. In S. M. Brudzynski (Eds.), *Handbook of Behavioral Neuroscience* (pp. 187-197). Academic Press.

Slevc, L. R., Davey, N. S., Buschkuehl, M., & Jaeggi, S. M. (2016). Tuning the mind: Exploring the connections between musical ability and executive functions. *Cognition*, *152*, 199-211. https://doi.org/10.1016/j.cognition.2016.03.017

Soranzo, A., & Grassi, M. (2014). PSYCHOACOUSTICS: a comprehensive MATLAB toolbox for auditory testing. *Frontiers In Psychology, 5,* 1-13. https://doi.org/10.3389/fpsyg.2014.00712

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers, 31*(1), 137-149. https://doi.org/10.3758/bf03207704

Strachan, J. W. A., Sebanz, N., & Knoblich, G. (2019). The role of emotion in the dyad inversion effect. *PLOS ONE*, *14*(7), e0219185. https://doi.org/10.1371/journal.pone.0219185

Strait, D. L., Kraus, N., Skoe, E., & Ashley, R. (2009). Musical experience promotes subcortical efficiency in processing emotional vocal sounds. *Annals Of The New York Academy Of Sciences*, *1169*(1), 209-213. https://doi.org/10.1111/j.1749-6632.2009.04864.x

Swaminathan, S., & Schellenberg, E. G. (2018). Musical competence is predicted by music training, cognitive abilities, and personality. *Scientific Reports, 8*(1). https://doi.org/10.1038/s41598-018-27571-2

Swaminathan, S., & Schellenberg, E. G. (2017). Musical competence and phoneme perception in a foreign language. *Psychonomic Bulletin & Review, 24*(6), 1929-1934. https://doi.org/10.3758/s13423-017-1244-5

Swaminathan, S., & Schellenberg, E. G. (2019). Musical ability, music training, and language ability in childhood. *Journal of Experimental Psychology: Learning, Memory, and Cognition.* Advance online publication. https://doi.org/10.1037/xlm0000798

Swaminathan, S., Schellenberg, E. G., & Venkatesan, K. (2018). Explaining the association between music training and reading in adults. *Journal Of Experimental Psychology: Learning, Memory, And Cognition*, *44*(6), 992-999. https://doi.org/10.1037/xlm0000493

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2004). Decoding speech prosody: Do music lessons help?. *Emotion*, *4*(1), 46-64. https://doi.org/10.1037/1528-3542.4.1.46

Trimmer, C. G., & Cuddy, L. L. (2008). Emotional intelligence, not music training, predicts recognition of emotional speech prosody. *Emotion,* *8*(6), 838-849. https://doi.org/10.1037/a0014080

Wagenmakers, E., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J. Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., … Morey, R. D. (2018a). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, *25*(1), 58-76. https://doi.org/10.3758/s13423-017-1323-7

Wagenmakers, E., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J. Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018b). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, *25*(1), 35-57. https://doi.org/10.3758/s13423-017-1343-3

Wagenmakers, E., Verhagen, J., & Ly, A. (2016). How to quantify the evidence for the absence of a correlation. *Behavior Research Methods*, *48*(2), 413-426. https://doi.org/10.3758/s13428-015-0593-0

Wagner, H. (1993). On measuring performance in category judgment studies of nonverbal behavior. *Journal Of Nonverbal Behavior*, *17*(1), 3-28. https://doi.org/10.1007/bf00987006

Warren, J. E., Sauter, D. A., Eisner, F., Wiland, J., Dresner, M. A., Wise, R. J., Rosen, S., & Scott, S. K. (2006). Positive emotions preferentially engage an auditory-motor "mirror" system. *Journal of Neuroscience*, *26*(50), 13067-13075. https://doi.org/10.1523/jneurosci.3907-06.2006

Wechsler, D. (2008). *WAIS-III: Manual da Escala de Inteligência de Wechsler para Adultos – 3ª Edição.* Lisboa: CEGOC-TEA.

Wong, P. C. M., Skoe, E., Russo, N. M., Dees, T., & Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience*, *10*(4), 420-422. https://doi.org/10.1038/nn1872

Zhang, J. D., Susino, M., McPherson, G. E., & Schubert, E. (2018). The definition of a musician in music psychology: A literature review and the six-year rule. *Psychology Of Music*. Advance online publication. https://doi.org/10.1177/0305735618804038

CHAPTER 3

Can musical ability be tested online?

Correia, A. I., Vincenzi, M., Vanzella, P., Pinheiro, A., Lima, C. F., & Schellenberg, E. G. (2022). Can musical ability be tested online? *Behavior Research Methods, 54*(2), 955-969. https://doi.org/10.3758/s13428-021-01641-2

Abstract

We sought to determine whether an objective test of musical ability could be successfully administered online. A sample of 754 participants was tested with an online version of the Musical Ear Test (MET), which had Melody and Rhythm subtests. Both subtests had 52 trials, each of which required participants to determine whether standard and comparison auditory sequences were identical. The testing session also included the Goldsmiths Musical Sophistication Index (Gold-MSI), a test of general cognitive ability, and self-report questionnaires that measured basic demographics (age, education, gender), mind-wandering, and personality. Approximately 20% of the participants were excluded for incomplete responding or failing to finish the testing session. For the final sample (N=608), findings were similar to those from in-person testing in many respects: (1) the internal reliability of the MET was maintained, (2) construct validity was confirmed by strong associations with Gold-MSI scores, (3) correlations with other measures (e.g., openness to experience, cognitive ability, mind-wandering) were as predicted, (4) mean levels of performance were similar for individuals with no music training, and (5) musical sophistication was a better predictor of performance on the Melody than on the Rhythm subtest. In sum, online administration of the MET proved to be a reliable and valid way to measure musical ability.

3.1. Introduction

For most of us, the Internet is part of everyday life. Over half of the world's population (51%) now uses the Internet, and this proportion is even higher for young people (69%), especially those living in developed countries (98%; International Telecommunication Union, 2020). The COVID-19 pandemic increased the amount of time people spend on the Internet while restricting in-person contact, making online testing an attractive option for psychological research. Even before the pandemic, online methods were used increasingly as an alternative to in-person research conducted in the laboratory (e.g., Chetverikov & Upravitelev, 2015; Houben & Wiers, 2008; Milne et al., 2020; Smith & Leigh, 1997; Taherbhai et al., 2012), while the emergence of a number of online platforms provided new tools for recruitment and testing (e.g., Gosling & Mason, 2015; Grootswagers, 2020).

Although there are legitimate concerns about online testing, such as lack of control over characteristics of the samples and testing contexts (e.g., Birnbaum, 2004; Krantz & Dalal, 2000), online studies have several features that make them equivalent or even superior to in-person testing (e.g., Casler et al., 2013; Dandurand et al., 2008; Gosling et al., 2004). First, data quality can be similar, in the sense that the findings are similar. Second, Internet samples can be more diverse and representative of the general population in terms of age, gender, and socioeconomic status, particularly when compared to samples comprised solely of college students registered in introductory psychology courses. Third, access to relatively rare target audiences, such as musicians, tends to be easier. Fourth, participants may feel more comfortable and act more naturally at home than when they come to a laboratory. Fifth, building an online experiment, recruiting participants, and collecting data can be more efficient in terms of time and costs, especially when responses are scored and recorded automatically on the hosting platform. Finally, online experiments are not limited to the space and time constraints of a laboratory.

Despite these benefits, online testing needs specific exclusion criteria, careful experimental designs that maximize control (e.g., Gosling et al., 2004), and appropriate motivational strategies (e.g., promising feedback at the end) to improve the likelihood that participants complete the whole experiment. Auditory research, and temporally based experimental tasks in general, can be particularly challenging, because compared to the laboratory, online testing occurs in contexts that are more variable and uncontrolled in terms of extraneous sounds, technical aspects of stimulus presentation, and potential interruptions (e.g., Milne et al., 2020). Although this variability can be reduced by asking participants to follow specific instructions (e.g., to wear headphones), experimental control remains limited.

How similar are the findings from in-person and online experiments? Positive results come from an online study about reinforcement learning (Nussenbaum et al., 2020), which replicated a main effect of age that was reported in an earlier in-person study (Decker et al., 2016). In other developmental research, online data replicated a mediating role for abstract-reasoning ability in the link between age and model-based learning (Chierchia et al., 2019). In non-developmental research, Houben and Wiers (2008) found that an implicit-association test was effective at identifying alcohol-related associations whether it was administered online or in-person.

Although there is substantial evidence that simple tasks can be adapted reliably for online testing, an open question is whether longer and more cognitively demanding tasks can be adapted similarly. In one instance, Dandurand et al. (2008) adapted a complex problem-solving task (from Dandurand et al., 2004) for online testing. Across platforms, participants' performance was better when they observed or read instructions on how to solve the problem successfully, compared to when they were simply given feedback on their decisions. Nevertheless, online participants were less accurate in general than in-person participants, even though the testing format did not influence the main effect of the learning manipulation (i.e., no interaction).

In the present investigation, we used the platform *Gorilla* (http://www.gorilla.sc/; Anwyl-Irvine et al., 2020) to create an online version of an objective measure of musical ability—the Musical Ear Test (MET). The MET is a listening test that has documented reliability and validity (Swaminathan et al., 2021; Wallentin et al., 2010a, 2010b). It is designed in the tradition of musical-*aptitude* (i.e., natural musical ability) tests, with two subtests, Melody and Rhythm, both of which require participants to determine, on multiple trials, whether two auditory sequences (a standard followed by a comparison) are identical. Musical-aptitude tests, dating back to the early 20th century (Bentley, 1966; Gordon, 1965; Seashore, 1919; Seashore et al., 1960; Wing, 1962), were designed to identify whether musically untrained individuals (primarily children) are likely to benefit from music lessons, based on the view that people with little natural ability would be unlikely in this regard. These older tests, as well as more recent tests of musical ability (Asztalos & Csapó, 2014; Fujii & Schlaug, 2013; Law & Zentner, 2012; Peretz et al., 2003, 2013; Ullén et al., 2014; Zentner & Strauss, 2017), all require same-different comparisons of two auditory events that differ in pitch (e.g., melody) or time (e.g., rhythm), or along other dimensions such as timbre and amplitude. In other words, the tests rely on core musical skills, specifically auditory short-term (working) memory and perceptual discrimination. As a broad phenotype, musical ability incorporates many other aspects of behavior (e.g., expert levels of performance, long-term memory for melodies) that are dependent on learning and practice. The goal of tests such as the MET is to measure musical ability in the absence of any formal training, and to do so objectively and quickly.

We also used *Gorilla* to run the entire testing session, which included measures of general cognitive ability and personality, and to create an online version of a self-report measure of musical behavior and expertise—the Goldsmiths Musical Sophistication Index (Gold-MSI; Lima et al., 2020; Müllensiefen, et al., 2014). The Gold-MSI served as our principal measure of construct validity. Virtually all developers of tests of musical ability report positive correlations with musical expertise as a means of documenting a test's validity (Asztalos & Csapó, 2014; Law & Zentner, 2012; Wallentin et al., 2010a; Zentner & Strauss, 2017; Ullén et al., 2014).

We compared response patterns from our online sample with previous studies that had large samples of participants: Swaminathan et al. (2021, $N = 523$) for the MET, and Lima et al. (2020, $N = 408$) for the Gold-MSI. Specifically, we compared the present sample with these comparison samples in terms of their psychometric characteristics, including internal reliability, construct validity, correlations between subtests, and correlations between musical ability and musical sophistication. We also tested for associations with demographic variables, cognitive ability, and personality, because previous studies have shown robust associations with these variables (e.g., Cooper, 2019; Greenberg et al., 2015; Kuckelkorn et al., 2021; Lima et al., 2020; Moreno et al., 2011; Swaminathan et al., 2021). Absolute levels of performance on our measures could vary across samples depending on the degree to which they differ in music training, age, cognitive ability, personality, education, and so on. In terms of age and education, Lima et al. tested Portuguese individuals from the general population who varied widely, whereas Swaminathan et al. tested Canadian undergraduates who varied minimally.

Because the Gold-MSI has a history of online *and* in-person testing (Correia et al., 2020; Greenberg et al., 2015; Lima et al., 2020; Müllensiefen et al., 2014; Schaal et al., 2015), we predicted that results from our online version of the test would be similar to those from the paper-and-pencil administration of Lima et al. (2020), with similar psychometric properties. We were less certain of the outcome with the online version of the MET, primarily because technological requirements were much greater for an objective listening test, which required participants to determine, on each of 104 trials, whether two auditory sequences were identical.

In short, our main objective was to determine whether the MET could be administered online successfully. Evidence of *success* required that the test's internal reliability would not be compromised by online administration, that performance would be correlated positively with musical expertise, and that musical ability would have positive associations with general cognitive ability. Moreover, musical expertise should be a better predictor of scores for the Melody subtest of the MET than for the Rhythm subtest, as it is with in-person testing (Swaminathan et al., 2021). Other findings from previous research (Swaminathan & Schellenberg, 2018; Butkovic et al., 2015) indicated that the online test's success would be further supported by a positive correlation with scores on one (and only one) dimension from the Big Five model of personality (McCrae & Costa, 1987; McCrae & John, 1992): openness-to-experience.

More novel aspects of the present study included our prediction that mind-wandering would be associated negatively with performance on the MET, because the MET required participants to concentrate for 18 min. One might also expect lower levels of mind-wandering among individuals who have taken music lessons for a longer period of time, because learning to play music requires much time, effort, and focus. Our use of the Gold-MSI as a measure of musical expertise allowed us to explore whether aspects of musical expertise other than training were predictive of performance, and whether their predictive power would vary across subtests. Previous studies of musical ability restricted tests of construct validity to associations with musicianship status, amount of daily practice, duration of music training, or involvement in professional music-related activities (Law & Zentner, 2012; Swaminathan et al., 2021; Ullén et al., 2014; Wallentin et al., 2010a). The Gold-MSI allowed us to examine whether musical ability would also be associated with active engagement with music, emotional responding to music, and self-reports of singing and perceptual abilities. Such associations would confirm that the narrow range of abilities tested by the MET is predictive of a much broader range of musical abilities.

3.2. Method

3.2.1. Participants

A total of 754 participants were tested originally. We subsequently excluded participants who did not complete the MET (*n* = 100) or failed to respond on several trials on either the Melody or the Rhythm subtest, which we defined as more than 10 trials in total (*n* = 39) or more than 5 in a row (*n* = 7). The final sample included 608 participants (361 female, 243 male, 4 unreported) between 18 and 88 years of age (*M* = 34.2, *SD* = 15.1). Most had completed high school (*n* = 207) or had a university degree (bachelor's, *n* = 108, master's, *n* = 191, Ph.D., *n* =

58). Only three participants had less than 10 years of education. Education data were missing for 41 participants.

Participants were recruited primarily through snowball sampling and social-media posts, which read: *Do you like music? Do you know anyone who does? We are running an online study on personality and musical abilities. We are looking for listeners with all kinds of musical backgrounds.* A subsample of undergraduate students was recruited via email and received partial course credit for their participation. The experiment was available in four languages, and participants were instructed to complete it in their native language (Italian, *n* = 288; European Portuguese, *n* = 153; Brazilian Portuguese, *n* = 123; English, *n* = 44). Informed consent was collected from all participants, and ethical approval for the study protocol was obtained from the local Ethics Committee at ISCTE-IUL (reference 07/2021).

Participants varied widely in terms of music training. Half had no history of music lessons (*n* = 151) or a maximum of 2 years (*n* = 133), but 156 had 10 years or more. The training included private lessons (*n* = 123), or classes taught at university (*n* = 122) or in musical academies or conservatories (*n* = 84). Others (*n* = 85) were self-taught. On average, participants with music lessons started their training at the age of 11.4 years (*SD* = 7.1; range: 2 – 56). The relatively high proportion of participants with extensive backgrounds in music was presumed to stem from their personal interest in the study.

3.2.2. Measures

All tasks and questionnaires, created originally in English, were adapted for online testing using Gorilla Experiment Builder (Anwyl-Irvine et al., 2020). Validated translations of the measures (e.g., the Big Five Inventory in European-Portuguese and Italian) were used when available. When a task or questionnaire was not available for our target languages, instructions and items were translated by bilinguals who were native speakers and also fluent in English.

Online versions of the MET and the Gold-MSI are available on Gorilla for other researchers to use (https://app.gorilla.sc/openmaterials/218554).

3.2.2.1. Objective Behavioral Tests

Musical Ability. An online version of the Musical Ear Test (MET; Wallentin et al., 2010a) was used to evaluate music-perception abilities. We attempted to make the online experience as similar as possible to in-person testing, when the test is installed on a personal computer in the laboratory, and participants listen to stimuli over headphones and record their responses on an answer sheet. As in the original version, the online MET had two subtests, Melody and Rhythm (in that order), each of which had 52 trials. On each trial, participants listened to two short musical excerpts (a standard followed by a comparison) and made a yes/no judgement about whether the comparison was the same as the standard. On both subtests, half of the trials were *same* and half were *different*. The stimuli and order of presentation were the same as in the original test. All musical excerpts had the same metrical structure (4/4 time) and tempo (100 beats per minute). A lower-amplitude metronome sound indicated the underlying beat. Each subtest was preceded by two practice trials (one *same*, one *different*). Feedback was provided for practice trials but not for test trials. Detailed descriptions of MET stimuli are provided in Swaminathan et al. (2021).

In the original test, all instructions and trials are presented via an 18-min digital audio file, with task instructions and the number of each trial provided by a male speaker. Trials are not self-paced. Rather, participants are given a brief window after each trial (1500 ms for melodic trials, 1659 to 3230 ms for rhythmic trials) to respond by checking *yes* or *no* on a response sheet. In our online adaptation of the MET, instructions and trial numbers were converted to text that participants read. The actual stimuli from each trial were digitally copied from the original audio file and the duration of the inter-stimulus intervals was preserved, such that the total duration (approximately 20 min) of the MET was identical to the in-person version. The trial number and the question (e.g., *Are the melodic phrases identical?)* were visible on the screen from the beginning of each trial until the participant responded. Immediately after the audio stimulus ended, two buttons—labelled *Yes* and *No*—appeared, and participants had a few moments to make their response by clicking the appropriate button. Examples of MET stimuli are illustrated in Figure 3.1 in musical notation.

To enhance the online testing experience, we provided a progress bar at the bottom of the screen throughout both subtests, such that participants could monitor where they were in relation to the beginning and end of the subtest. We also provided feedback at the end of the test about the participant's performance, which was calculated as the total number of correct responses on the Melody and Rhythm subtests. For statistical analyses, a Total score was also calculated as the sum.

General Cognitive Ability. Our measure of general cognitive ability (hereafter *cognitive ability*) was the Matrix Reasoning Item Bank (MaRs-IB; Chierchia et al., 2019), an online test of abstract (nonverbal) reasoning modeled after Raven's Advanced Progressive Matrices (Raven, 1965). On each of 80 trials, a 3 x 3 matrix was presented on the computer screen. Eight of nine cells contained abstract shapes, but the ninth (bottom-right) cell was always empty. Participants' task was to complete the matrix by choosing one of four alternatives. Two examples are provided in Figure 3.2. Associations among shapes could vary on a single dimension for the simplest trials (e.g., color), but on up to four dimensions (e.g., color, size, shape, and location) for more difficult trials.

Figure 3.1. Example Trials from the MET Melody and Rhythm Subtests. Reprinted by permission from Springer, *Behavior Research Methods*, "The Musical Ear Test: Norms and correlates from large sample of Canadian undergraduates," Swaminathan, Kragness, & Schellenberg (2021), advance online publication, 11 March 2021, doi: 10.3758/s13428-020-01528-8.

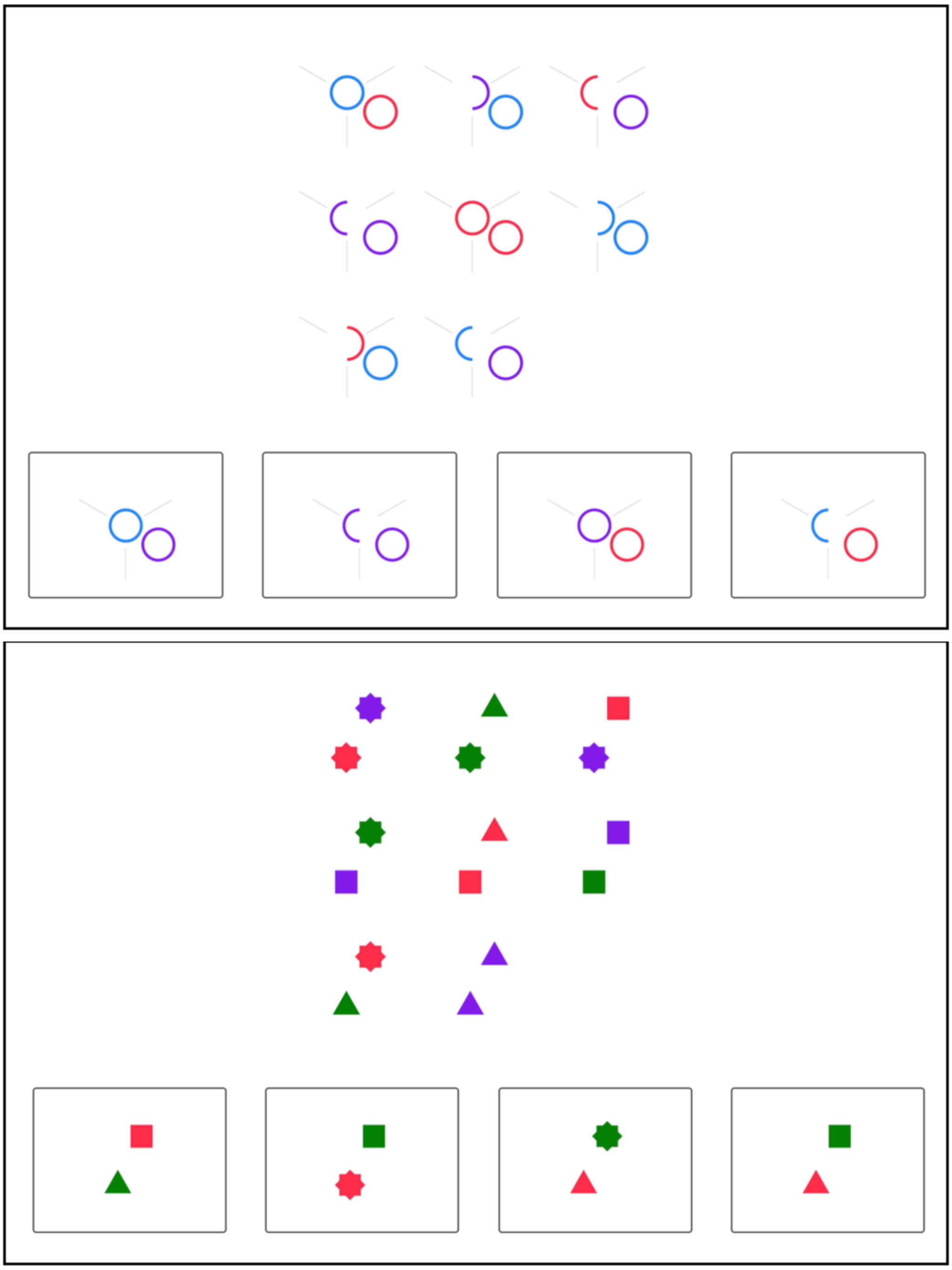

Figure 3.2. Two Example Trials from the Matrix Reasoning Item Bank (MaRs-IB). The Third and Fourth Options are the Correct Responses for the Upper and Lower Examples, Respectively.

On each trial, before the matrix was presented, a 500-ms fixation cross appeared in the middle of the screen, followed by a 100-ms white screen. Participants then had up to 30 s to look at the matrix and select a response. The trial ended earlier when participants responded. If no response was provided after 25 s, a clock appeared and indicated the time remaining.

The order of the trials was the same for all participants. The first five items were relatively easy so as to familiarize participants with the task. Although the duration of the entire task was fixed at 8 min, participants were not informed of the task duration or the number of trials—only that they had up to 30 s to complete each trial. If they completed the 80 trials in less than 8 min, the trials were re-presented again in the same order but responses from the second round were not considered in calculating scores. Scores were calculated as the proportion of the total number of responses given by the participant that were correct. For the statistical analyses, proportions were logit transformed.

3.2.2.2. Questionnaires

Musical Expertise. Our principal measure for tests of construct validity was the Gold-MSI (Müllensiefen et al., 2014), a self-report questionnaire of musical expertise and behavior. The Gold-MSI has 38 items that evaluate different behaviors related to music (e.g., *I spend a lot of my free time doing music-related activities*). Although the items are mixed in terms of order of presentation, for scoring purposes they are grouped to form five subtests: Active Engagement (9 items), Perceptual Abilities (9 items), Music Training (7 items), Singing Abilities (7 items), and Emotions (6 items). A General Musical Sophistication factor is also calculated from 18 items that are representative of the five subtests. For the first 31 items, participants judge how much they agree with each statement on a 7-point rating scale (1 = *completely disagree*, 7 = *completely agree*). For the final seven items, participants select one of seven alternatives from an ordinal scale that varies from item to item. For example, the scale for the statement *I listen attentively to music for…* had options ranging from 1 (*0 - 15 min per day*) to 7 (*4 hours or more per day*).

For European-Portuguese participants, we created an online version of a published translation of the Gold-MSI that has good psychometric properties (Lima et al., 2020). For the Italian translation, items from the original English version were translated to Italian independently by two translators, both of whom were native speakers of Italian, fluent in English, experienced in translating questionnaires, and experts in the psychology of music. The goal was conceptual equivalence rather than a literal translation. Discrepancies between translations were resolved by discussion to create a single version, which was, in turn, evaluated by two independent colleagues for clarity of expression and whether the translation from English was appropriate. The Italian version was then back-translated by a native speaker of English, who was fluent in Italian and a scholar of psychology and music. Inconsistencies between the back-translation and the original Gold-MSI were discussed and resolved among the three translators, who also consulted with two additional experts from the discipline. Finally, 10 participants completed the Italian translation of the Gold-MSI and confirmed that the items were clear.

For the Brazilian-Portuguese version, a native speaker, who was also fluent in English and an expert in the psychology of music, made minor modifications to the European-Portuguese version. To ensure that each modification was consistent with the original Gold-MSI, she first checked the English version. Such modifications included the progressive tense (*I am hearing* translated to *estou ouvindo* instead of *estou a ouvir*), the second-person pronoun (replacing *tu* with *você*), some Brazilian-Portuguese idioms, and minor changes in spelling.

Cronbach's alphas for the entire sample and for the previously unpublished (Italian and Brazilian-Portuguese) translations of the Gold-MSI are provided in Supplementary Table 3.1. In general, internal reliability was similar to the comparison sample (Lima et al., 2020), except for a lower alpha in the present sample for the Emotions subtest. Internal reliability was maintained for the previously unpublished translations.

Personality. Personality traits were evaluated with the Big Five Inventory (BFI). The BFI is a self-report questionnaire with 44 items that assess five dimensions of personality: Openness-to-Experience (10 items), Conscientiousness (9 items), Extroversion (8 items), Agreeableness (9 items), and Neuroticism (8 items). Items are mixed in terms of presentation order. Participants rated how much each expression describes them using a five-point rating scale (1 = *disagree strongly*, 5 = *agree strongly*).

The BFI was published initially in English (John & Srivastava, 1999), and translated subsequently into European-Portuguese (Brito-Costa et al., 2015) and Italian (Ubbiali et al., 2013). We created a Brazilian-Portuguese version by modifying the European-Portuguese version, double-checking the original English version for fidelity. Cronbach's alphas for the BFI were acceptable and are provided in Supplementary Table 3.2.

Mind Wandering. As a measure of sustained attention and ability to focus, participants completed the Mind-Wandering Questionnaire (MWQ, Mrazek et al., 2013), a 5-item scale with good psychometric properties that evaluated trait levels of mind-wandering (e.g., *I have difficulty maintaining focus on simple or repetitive work*). Participants rated how much they agreed with each sentence on a scale that ranged from 1 (*almost never*) to 6 (*almost always*). Cronbach's alphas for the MWQ were good and are provided in Supplementary Table 3.2.

3.2.3. Procedure

Participants completed all tasks and questionnaires in one testing session. Access to the experiment was initially provided with a hyperlink posted on social media (e.g., Facebook, Twitter, LinkedIn), which was accompanied by a brief description of the study, including its duration of approximately 40 min. The description also specified that participants should complete the testing session in a quiet room with a stable internet connection, use headphones, and turn off sound notifications from other devices and applications (e.g., e-mail, phone messages).

The online testing session began with informed consent and some basic demographic questions (e.g., age, gender, education). Participants then completed the self-report questionnaires, which were administered in a fixed order (MWQ, Gold-MSI, and BFI). After the questionnaires, participants were tested on the MaRs-IB and finally the MET. At the end of the study, participants were given feedback about their scores on the personality, musical-sophistication, and musical-ability measures. A final open-ended question asked participants to describe any problems that might have occurred during the testing session. Some participants reported minor technical difficulties, related primarily to the stability of their Internet connection, but there were otherwise no systematic problems.

3.3. Results

The complete data file is provided in Supplementary Materials. As in the reports from the comparison samples (Lima et al., 2020; Swaminathan et al., 2021), the statistical analyses incorporated standard frequentist null-hypothesis testing, as well as Bayesian analyses conducted with JASP version 0.14.1 (JASP Team, 2020) using default priors.[2] Because of the large sample, very small effects were statistically significant with null-hypothesis testing. For example, with $N = 608$, correlations greater than .08 in absolute value were significant with $p < .05$. We considered small associations to be reliable only if they also passed a conventional threshold for what is considered *substantial* evidence using Bayesian statistics (Jarosz & Wiley, 2014; Jeffreys, 1961). Specifically, when the Bayes factor (BF_{10}, reported here with 3-digit accuracy) was greater than 3.00, the observed data were at least three times more likely under the alternative than the null hypothesis. Lower values ($1.00 < BF_{10} < 3.00$) indicated that the data provided evidence for the alternative hypothesis that was considered to be weak or anecdotal. If $BF_{10} < 1.00$, the observed data provided evidence that favored the null hypothesis

[2] Correlations, stretched beta prior width = 1; *t*-tests, zero-centered Cauchy prior with scale parameter 0.707; linear regressions, JZS prior of $r = .354$; Wagenmakers et al., 2018a, 2018b; Wagenmakers et al., 2016).

in a reciprocal manner (i.e., substantial evidence when $BF_{10} < .333$). More extreme values provided strong ($BF_{10} > 10.0$ or $< .100$), very strong ($BF_{10} > 30.0$ or $< .033$), and decisive ($BF_{10} > 100.0$ or $< .010$) evidence for either the alternative or null hypothesis, respectively.

Initial analyses documented how the present online sample of participants differed from comparison samples in terms of gender, age, and music training. Detailed statistics are provided in Supplementary Materials. The present sample had a larger proportion of participants who were men, and the mean age was higher than in Swaminathan et al. (2021) but similar to Lima et al. (2020). Mean levels of music training were higher in the present sample than in both comparison samples.

Swaminathan et al. (2021) did not report personality data, and their sample of undergraduates varied minimally in terms of education. Comparisons with the sample from Lima et al. (2020) revealed that the present sample had lower mean levels of education. For personality (Supplementary Table 3.3), the two samples differed for each trait, with the present sample scoring higher on openness-to-experience and neuroticism, but lower on agreeableness, extroversion, and conscientiousness.

The main analyses focused on musical ability, musical experience, and their correlates, including demographics (age, gender, education), cognitive ability, personality, and mind-wandering. Pairwise correlations among potential predictors are provided in Supplementary Table 3.4. We had no hypotheses about the testing language of the online study, and exploratory analyses confirmed that musical ability did not vary as a function of language when individual differences in age, education, cognitive ability, and openness-to-experience were held constant. In fact, for the Melody subtest, the Rhythm subtest, and Total scores of the MET, the observed data provided substantial evidence for the null hypothesis (all $BF_{10} < .250$). Testing language was not considered further.

3.3.1. Musical Expertise

Because of the large number of musicians in the current sample, mean scores were higher than they were in Lima et al. across subtests and the General Factor, *p*s $< .001$, all $BF_{10} > 100$ (Supplementary Table 3.1). As in the comparison sample and elsewhere (Müllensiefen et al., 2014), pairwise correlations among Gold-MSI scores were all positive, and the observed data provided decisive evidence for an association in each instance (Supplementary Table 3.5). Examination of correlations between Gold-MSI scores and potential predictor variables revealed a relatively small number of instances in which the observed data provided substantial or stronger evidence for an association (Supplementary Table 3.6).

For demographic variables (age, gender, education), there was decisive evidence of a negative association between age and scores on the Emotions subtest. There was also strong evidence that men had more Music Training than women, and substantial evidence for a male advantage on the General Factor. Cognitive ability had no significant associations with Gold-MSI scores, and the observed data provided substantial (or strong) evidence for the null hypothesis for all subtests. As expected, there was strong evidence for a small, negative association between mind-wandering and the Music Training subtest, but mind-wandering was not associated with any other Gold-MSI score. For personality, openness-to-experience was associated decisively and positively with all Gold-MSI scores (*r*s $\geq .4$). The observed data also provided decisive and substantial evidence, respectively, for positive but small associations between extroversion and Singing Abilities, and between agreeableness and Music Training (*r*s $\leq .2$).

3.3.2. Musical Ability

Statistics from tests of internal reliability for the online MET are provided in Table 3.1. Cronbach's alphas were virtually identical to those reported by the test's developers (Wallentin et al., 2010b), and higher than those reported in the comparison sample (Swaminathan et al., 2021). Split-half (odd-even) reliabilities (Spearman-Brown formula) were also considerably higher than those reported by Swaminathan et al. In short, the internal reliability of the MET was not compromised by the online testing format.

Descriptive statistics for Melody, Rhythm, and Total scores are provided in Table 3.2. For the entire sample, the observed means were higher than those reported by Swaminathan et al. (2021) for Melody, Rhythm, and Total scores, as confirmed by independent-samples *t*-tests, $ts(1129) = 5.06$, 5.90, and 6.23, respectively, $ps < .001$, all $BF_{10} > 100$. These findings were not meaningful, however, because of sample differences in musicianship. To rectify this problem, we gave separate consideration to individuals with no music training (see Table 3.2). For these participants, mean performance did not differ from that reported previously on the Melody subtest, $p = .202$, $BF_{10} = .263$, the Rhythm subtest, $p = .053$, $BF_{10} = .725$, or for Total scores, $p = .064$, $BF_{10} = .625$, although evidence favoring the null hypothesis was substantial only for the Melody subtest. In any event, online-generated scores were comparable to in-person scores when they were expected to be comparable.

Table 3.1. Reliability Statistics, Including Cronbach's Alpha and Split-Half (Odd-Even) Correlations (Spearman-Brown Formula), for Scores on the MET. For Comparison Purposes, Values from Two Previous Reports are Provided

	Melody	Rhythm	Total
Current Online Sample (*N* = 608)			
Cronbach's Alpha	.82	.70	.85
Split-Half Correlation	.84	.75	.87
Swaminathan et al. (2021, *N* = 523)			
Cronbach's Alpha	.73	.62	.78
Split-Half Correlation	.71	.68	.78
Wallentin et al. (2010b, *N* = 60)			
Cronbach's Alpha	.82	.69	.85

Table 3.2. Descriptive Statistics for Scores on the MET. For Comparison Purposes, Values from Swaminathan et al. (2021) are Provided

	Current Online Sample			Swaminathan et al. (2021)		
Whole Sample						
	N	*M*	*SD*	*N*	*M*	*SD*
Melody	608	37.88	6.60	523	36.05	5.36
Rhythm	608	38.29	5.35	523	36.47	4.94
Total	608	76.17	10.54	523	72.52	8.89
No Music Training						
	n	*M*	*SD*	*n*	*M*	*SD*
Melody	151	34.91	6.44	189	34.15	4.41
Rhythm	151	36.66	5.79	189	35.56	4.68
Total	151	71.56	10.90	189	69.71	7.48

As one would expect, Melody and Rhythm scores were positively and decisively correlated, $r = .551$, $N = 608$, $p < .001$, $BF_{10} > 100$, with the magnitude of the association no different from that reported by Swaminathan et al. (2021), $r = .489$, $p = .154$, and Wallentin et al. (2010a), $r = .520$, $p = .754$.[3] As in the earlier reports, the data provided substantial evidence that performance did not differ between subtests, $BF_{10} = .214$.

3.3.2.1. Demographics, Cognitive Ability, Mind Wandering, and Personality

Correlations between MET scores and demographic variables, cognitive ability, mind wandering, and personality are provided in Table 3.3. The observed data provided decisive evidence that as listeners increased in age, education, or cognitive ability, performance on the

[3] Comparisons of the magnitude of correlations were conducted with Psychometrica (https://www.psychometrica.de/correlation.html).

MET (i.e., Melody, Rhythm, and Total scores) tended to improve as well. The one exception was the association between cognitive ability and Melody scores, for which the data provided substantial rather than decisive evidence. The correlation with cognitive ability was also higher for the Rhythm than for the Melody subtest, $z = 2.87$, $p = .004$.

Table 3.3. Pairwise Associations (Pearson Correlations and Bayes Factors) Between Scores on the MET and Demographic Variables, Cognitive Ability, Mind-Wandering, and Personality

		Melody	Rhythm	Total
Age	r	.206	.167	.214
	BF_{10}	>100	>100	>100
Gender	r	.099	.029	.077
	BF_{10}	1.01	.066	.306
Education	r	.209	.200	.232
	BF_{10}	>100	>100	>100
Cognitive Ability	r	.131	.239	.204
	BF_{10}	9.84	>100	>100
Mind-Wandering	r	-.122	-.060	-.107
	BF_{10}	4.60	.153	1.63
Openness	r	.241	.182	.243
	BF_{10}	>100	>100	>100
Conscientiousness	r	.068	.030	.058
	BF_{10}	.210	.067	.142
Extroversion	r	.065	.069	.076
	BF_{10}	.180	.218	.288
Agreeableness	r	.092	.060	.088
	BF_{10}	.650	.151	.527
Neuroticism	r	-.101	-.018	-.072
	BF_{10}	1.11	.056	.245

Note. Gender was dummy-coded (Females = 0, Males = 1). *N*s = 608 except for Education, $n = 566$.

For mind wandering, there was substantial evidence for a negative association with scores on the Melody subtest, but no evidence of an association with Rhythm or Total scores. Nevertheless, the magnitude of the association was not significantly stronger for Melody than for Rhythm, $p > .1$. For personality, the observed data provided decisive evidence for positive associations between openness-to-experience and MET performance, but no evidence for associations with any other personality variable. In fact, all Bayes factors were below one with a single exception, and for two personality traits (conscientiousness, extroversion), the observed data provided substantial evidence for the null hypothesis.

3.3.2.2. Musical Expertise and Music Training

Our main tests of construct validity involved correlations between scores on the MET and those from the subtests and General Factor from the Gold-MSI, which are provided in Table 3.4. All correlations were positive and statistically significant with $p < .001$, with the observed data providing decisive evidence for an association in each instance, except for the association between the Emotions subtest and Rhythm scores, which was strong but not decisive.

Table 3.4. Pairwise Associations (Pearson Correlations and Bayes Factors) Between Scores on the MET and Scores on the Gold-MSI (N = 608).

		Melody	Rhythm	Total
Active Engagement	r	.303	.186	.284
	BF_{10}	>100	>100	>100
Perceptual Abilities	r	.459	.320	.450
	BF_{10}	>100	>100	>100
Music Training	r	.491	.296	.458
	BF_{10}	>100	>100	>100
Singing Abilities	r	.406	.259	.386
	BF_{10}	>100	>100	>100
Emotions	r	.206	.141	.201
	BF_{10}	>100	22.5	>100
General Factor	r	.504	.307	.471
	BF_{10}	>100	>100	>100

In the comparison sample (Swaminathan et al., 2021), music training proved to be a better predictor of Melody than of Rhythm scores. Our Gold-MSI scores showed a similar pattern. For Perceptual Abilities, Music Training, Singing Abilities, and the General Factor, correlations with the Melody subtest were higher than those for the Rhythm subtest, zs > 4, ps < .001. The same finding was weaker yet still evident for Active Engagement, $z = 3.16$, $p = .002$, but not for the Emotions subtest, $p = .086$.

Additional analyses focused solely on the Music Training subtest. Associations between Music Training and MET scores (see Table 3.4) were higher than those in the comparison sample (Swaminathan et al., 2021), which could be due to differences in measuring training, and/or a consequence of greater variability due to the higher proportion of musicians in the present sample. The correlations were somewhat lower than correlations between MET scores and current daily practice reported by Wallentin et al. (2010a, Experiment 3), a likely consequence of differences in measurement.

We also asked whether performance on the MET was associated with the age at which music training began. As in Swaminathan et al. (2021), we considered only participants who had any training ($n = 415$) and divided them into two groups: those who started by age 7—*early starters* ($n = 120$)—and those who started at an older age—*late starters* ($n = 295$). This split was theoretically motivated, based on the proposal of a sensitive period that extends up to 7 years of age, during which plasticity is greater and music training is presumed to have a stronger impact on development (Penhune, 2019, 2020; Penhune & De Villiers-Sidani, 2014).

The results were similar to those reported in the comparison sample (Swaminathan et al., 2021). Early starters had higher scores than late starters on the Melody subtest, $t(413) = 3.18$, $p = .002$, $BF_{10} = 14.7$, and on Total scores, $t(413) = 2.96$, $p = .003$, $BF_{10} = 7.82$, but not on the Rhythm subtest, $p = .076$, $BF_{10} = .543$. Nevertheless, early starters also had more Music Training, $t(413) = 4.11$, $p < .001$, $BF_{10} > 100$. When Music Training was held constant, the advantage for early starters disappeared for the Melody subtest, $p = .078$, $BF_{10} = .577$, and for Total scores, $p = .083$, $BF_{10} = .527$, although the observed data did not provide strong evidence for the null hypothesis.

3.3.2.3. Multiple Regression Analysis

In the final set of analyses, we used multiple regression to determine which correlates made independent contributions in predicting performance on the MET. Specifically, we modeled MET Melody, Rhythm, and Total scores from a linear combination of variables, each of which had a reliable simple association with MET scores: age, education, cognitive ability, mind-wandering, openness-to-experience, and the Gold-MSI subtests. The results are summarized in Table 3.5. For the Melody subtest, the Rhythm subtest, and Total scores, the overall model was significant, with independent and positive partial associations with age, education, cognitive ability, and the Perceptual Abilities and Music Training subtests from the Gold-MSI.

In the Bayesian counterpart to multiple regression, we first identified which model—out of all possible models—was most likely given the observed data. For the Melody subtest and for Total scores, it was a model that included age, education, cognitive ability, Perceptual Abilities, and Music Training—a finding that corroborated the frequentist results. We calculated a Bayes factor for each predictor by removing them from the model one at a time. As shown in Table 3.5, the observed data provided decisive evidence for the inclusion of Perceptual Abilities and Music Training in the model, and very strong (Melody) or decisive (Total) evidence for including cognitive ability and age. For education, however, the Bayes factor was less than 3. We calculated BF_{10} for the other (excluded) five variables by adding each to the model one at a time. For each variable, the observed data provided substantial evidence for the null hypothesis. In other words, the observed data were more likely with a model that did *not* include these variables.

For the Rhythm subtest, the best model of the data included age, cognitive ability, Perceptual Abilities and Music Training. The observed data provided decisive evidence for the inclusion of age, cognitive ability, and Perceptual Abilities in the model, but only substantial evidence for including Music Training. For the other six variables, the observed data provide substantial evidence for the null hypothesis with one exception: they were more or less equally likely with a model that included or excluded education.

Table 3.5. Multiple Regression Results Predicting MET Scores from Age, Education, Openness-to-Experience, Cognitive Ability, Mind Wandering, and the Five Gold-MSI Subtests

	Melody			Rhythm			Total		
Model									
R^2	.332			.210			.335		
Adjusted R^2	.320			.196			.323		
$F(10, 555)$	27.63			14.76			27.98		
p	<.001			<.001			<.001		
Predictors	ß	p	BF_{10}	ß	p	BF_{10}	ß	p	BF_{10}
Age	.154	<.001	61.7	.159	<.001	>100	.177	<.001	>100
Education	.098	.016	1.43	.089	.045	.760	.107	.009	2.14
Cognitive Ability	.145	<.001	>100	.259	<.001	>100	.222	<.001	>100
Mind Wandering	.010	.802	.129	.013	.751	.146	.013	.739	.131
Openness	-.027	.523	.129	-.005	.918	.160	-.019	.648	.125
Active Engagement	.049	.347	.218	.077	.174	.306	.070	.178	.357
Perceptual Abilities	.177	.003	>100	.174	.008	>100	.199	<.001	>100
Music Training	.305	<.001	>100	.128	.019	6.62	.256	<.001	>100
Singing Abilities	.053	.337	.232	-.019	.749	.146	.023	.673	.155
Emotions	-.002	.972	.140	-.006	.908	.169	-.004	.931	.148

3.4. Discussion

We sought to determine if an established and validated test of musical ability could be administered online successfully. Although approximately 20% of the sample who started the testing session did not complete it or provide useable data, this level of attrition is not surprising because there was no compensation or incentive for participants to complete the session, other than to receive feedback about their personality, musical expertise, and musical ability. Moreover, the testing session was relatively long and, unlike in a laboratory, there were no research assistants to witness a participant's decision to discontinue. In any event, the findings were otherwise unequivocally positive. Indeed, the results for the MET were both novel and noteworthy because it is an objective listening test of musical ability that, to our knowledge, has not been adapted previously for online testing.

The Gold-MSI served as our main variable for testing construct validity and as a proof of concept—that the present sample of online participants would respond similarly to a sample of participants tested in a more traditional format (Lima et al., 2020). Indeed, response patterns to the online Gold-MSI were very similar to those reported previously. For example, the internal reliability of the test was similar across formats except for the Emotions subtest. As in the earlier study, age was correlated negatively with the Emotions subtest, although Lima et al. found a negative correlation between age and *all* Gold-MSI subtests. Discrepancies in response patterns between samples could stem from differences in music training. Compared to the previous study, we had a larger subsample of participants with very high levels of music education; one-quarter of our sample (25.6%) had 10 or more years of music lessons, whereas in Lima et al., the figure was closer to one-twentieth (5.6%). Because increases in musical experience must be accompanied by increases in age, a negative association between age and Gold-MSI scores would be less likely in our online sample. Despite these differences in samples, correlations among Gold-MSI subtests, and between Gold-MSI scores and personality variables, were similar across testing formats.

One null finding was that there was little evidence of an association between cognitive ability and the Music Training subtest from the Gold-MSI. In childhood, music training is often correlated positively with cognitive ability (Corrigall et al., 2013; Corrigall & Schellenberg, 2015; Kragness et al., 2021; Schellenberg, 2006, 2011; Schellenberg & Mankarious, 2012; Swaminathan & Schellenberg, 2020). In adulthood, however, such associations tend to be weaker (Lima & Castro, 2011; Schellenberg, 2006). When matrices-type tests of cognitive ability, such as Raven's test and the test used in the present sample (MaRs-IB), are given to students from an introductory psychology course, positive associations with music training are evident in some instances (Swaminathan et al., 2017, 2018, 2021; Swaminathan & Schellenberg, 2018) but not in others (Schellenberg & Moreno, 2010; Swaminathan & Schellenberg, 2017). These associations may become less likely in samples of older participants with a large proportion of professional musicians (Lima & Castro, 2011).

Turning now to our main focus, the MET, the internal reliability of the online version proved to be similar to, perhaps even better than in-person administration (Wallentin et al., 2010b; Swaminathan et al., 2021). Other results confirmed that: (1) the correlation between

Melody and Rhythm subtests did not differ across formats, (2) there was no difference in performance between subtests, and (3) when the present and comparison samples were equated for music training by focusing solely on participants with no training, average levels of performance were similar. Moreover, as in the comparison sample, there were no gender differences in performance on the MET. Finally, as in other samples, performance had a strong association with openness-to-experience, which was not evident for other dimensions of personality (Greenberg et al., 2015; McCrae & Greenberg, 2014; Swaminathan & Schellenberg, 2018; Thomas et al., 2016). In short, online testing did not compromise the reliability and validity of the MET.

Strong evidence of construct validity for our online version of the MET came from positive associations with scores on the Gold-MSI. Previous in-person studies documented that as degree of musicianship and amount of practice (Wallentin et al., 2010a) or duration of music training (Swaminathan et al., 2021) increases, so does performance on the MET. In the present investigation, associations with Music Training as measured by the Gold-MSI were somewhat higher than those of the comparison sample (Swaminathan et al., 2021), which we attribute to the relatively high variability of music training and the high proportion of professional musicians tested online. We also found positive associations between MET scores and other aspects of self-reported musical expertise measured by the Gold-MSI, namely Active Engagement, Emotions, Perceptual Abilities, and Singing Abilities. In the Gold-MSI validation study, Müllensiefen et al. (2014) reported a comparable pattern of associations using short beat-alignment and melodic-memory tasks. Our results extended these associations, indicating that musical skills and experience are multifaceted, and not limited to music lessons or playing an instrument. Moreover, even though the musical skills tested by the MET are based on auditory short-term (working) memory and perceptual discrimination, performance was predictive of a broad range of musical behaviors and expertise.

As in the comparison sample, we found no association between musical abilities and age-of-onset of music lessons after duration of music training was held constant. This finding raises the possibility that proposals of plasticity effects arising from early music training (Penhune, 2019, 2020; Penhune & De Villiers-Sidani, 2014) may be exaggerated. Indeed, longitudinal evidence in childhood shows that musical ability is independent of music training when levels of musical ability measured 5 years previously are taken into account (Kragness et al., 2021). Nevertheless, other findings reveal behavioral advantages and structural brain differences as a consequence of early training, even after accounting for duration of training (Bailey et al., 2014; Bailey & Penhune, 2010, 2012, 2013). Perhaps early onset of music training explains some musical abilities, such as rhythm synchronization and production abilities, but not other abilities, such as those measured by the MET.

As noted, one advantage of online recruitment is that it allowed for a large sample of motivated individuals, including many who likely participated because they identified as working musicians or musician-academics. Our sample was also heterogeneous in terms of age and education, which tend to vary minimally when participants are recruited from undergraduate courses in introductory psychology, as in the MET comparison sample (Swaminathan et al., 2021). Substantial variance in education meant that we had two variables to represent cognitive ability: the objective test as well as self-reports of education. The status of age and its relation to cognition is more ambiguous, because some abilities, such as processing speed, start to decline relatively early in life, whereas others continue to peak until after age 40 (Hartshorne & Germine, 2015). In any event, age, education and our online measure of cognitive ability were predictive of performance on the MET. In the comparison sample, MET scores were correlated positively with three different measures of cognitive ability: Digit Span Forward, Digit Span Backward, and Raven's tests. Thus, as with virtually any specific cognitive ability, individual differences in musical ability vary positively with general ability (Carroll, 1993), whether they are measured in-person or online.

Although the association between MET scores and cognitive abilities was consistent with previous research (e.g., Swaminathan et al., 2017, 2018, 2021; Swaminathan & Schellenberg, 2018), and strong even when other variables were held constant (Table 3.5), cognitive ability was a better predictor of scores on the Rhythm compared to the Melody subtest. Swaminathan et al. (2021, Table 8) also found evidence that general ability (i.e., working memory as measured by Digit Span Backward) was a better predictor of Rhythm than of Melody scores. By contrast, music training was a better predictor of Melody compared to Rhythm in the online *and* in-person samples, and this difference extended to other aspects of musical expertise measured by the Gold-MSI, specifically Active Engagement, Perceptual Abilities, Singing Ability, and the General Factor. In other words, performance on the Melody subtest appears to rely more on individual differences in exposure to music, whereas performance on the Rhythm subtest is more strongly associated with nonmusical individual differences. Swaminathan et al. (2021) suggested that this result might stem from the fact that the Rhythm subtest taps into a universal feature of music, whereas performance on the Melody subtest is more strongly influenced by exposure to pitch structures that are specific to Western music. Even in early childhood, 1 year of intensive music training improves melody discrimination more than it improves rhythm discrimination (Ilari et al., 2016).

Performance on the Melody subtest but not the Rhythm subtest was also linked to a lower level of mind-wandering, although this association disappeared when other predictors of Melody scores were held constant. In one previous study (Wang et al., 2015), highly trained musicians had an enhanced ability to sustain attention during a temporal-discrimination task (but not in a visual-discrimination task), and this advantage remained evident when cognitive ability was held constant. The association between musical ability and mind-wandering or sustained attention could be examined in more detail in future research.

Because the Gold-MSI subscales had considerable overlap (Supplementary Table 3.5), the multiple-regression analyses served to identify which subscales made independent contributions to predicting performance on the MET. In addition to the Music Training subscale, the Perceptual Abilities subscale was a robust predictor of Melody, Rhythm, and Total scores, and, in the case of Rhythm, even superior to Music Training. This finding is indicative of participants' meta-cognitive awareness of their musical ability: Individual differences in self-reports of music-perception skills, measured before taking the MET, were correlated with musical abilities measured subsequently and objectively.

The present study also had limitations. Although we asked participants to perform the experiment in a quiet environment and to avoid distractions, Internet testing made it difficult to control for extraneous sounds or potential interruptions, which remain a major challenge for online testing in general, and for auditory research in particular. Moreover, we did not include a task to ensure that participants used headphones (Milne et al., 2020; Woods et al., 2017). Although we strongly recommended that they used them throughout the experiment, it was not possible to verify whether they did.

In sum, the online version of the MET showed good internal reliability and appropriate levels of performance. Strong associations between the accuracy on the MET and musical sophistication and training, especially for the Melody subtest, were also consistent with studies using in-person testing of MET (Swaminathan et al., 2021). Finally, as expected, scores from online administration were correlated with personality (openness-to-experience), cognitive ability, and mind-wandering. Online testing also had advantages compared to the traditional in-lab testing, which have been noted by others (e.g., Casler et al., 2013; Gosling et al., 2004). For example, online recruitment allowed us to obtain a larger and more diverse sample compared to previous studies on musical abilities, including participants from different nationalities, a large number of professional musicians as well as nonmusicians, and participants who varied widely in age. Finally, the online format made it possible to recruit participants and collect data in very short time (approximately one month), because we were not limited by the space and time constraints of the laboratory.

To conclude, our findings showed that online administration of MET is a valid and reliable alternative to traditional in-person measurement of musical abilities. With greater worldwide access to the Internet and in-person restrictions imposed by the Covid-19 pandemic, there has been a growing interest in the development of Internet methods. This study contributes to the growing literature on the utility of online testing as an alternative, or complement, to laboratory testing for psychological research.

References

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods*, *52*(1), 388–407. https://doi.org/10.3758/s13428-019-01237-x

Asztalos, K., & Csapó, B. (2014). Online assessment of musical abilities in Hungarian primary schools—results of first, third and fifth grade students. *Bulletin of the International Kodály Society, 39*(1), 3–14.

Bailey, J. A., & Penhune, V. B. (2010). Rhythm synchronization performance and auditory working memory in early- and late-trained musicians. *Experimental Brain Research, 204*, 91–101. https://doi.org/10.1007/s00221-010-2299-y

Bailey, J. A., & Penhune, V. B. (2012). A sensitive period for musical training: Contributions of age of onset and cognitive abilities. *Annals of the New York Academy of Sciences, 1252*, 163–170. https://doi.org/10.1111/j.1749-6632.2011.06434.x

Bailey, J. A., & Penhune, V. B. (2013). The relationship between the age of onset of musical training and rhythm synchronization performance: Validation of sensitive period effects. *Frontiers in Auditory Cognitive Neuroscience, 7*, Article 227. https://doi.org/10.3389/fnins.2013.00227

Bailey, J. A., Zatorre, R. J., & Penhune, V. B. (2014). Early musical training: Effects on auditory motor integration and grey matter structure in ventral premotor cortex. *Journal of Cognitive Neuroscience, 26*(4), 755–767. https://doi.org/10.1162/jocn_a_00527

Bentley, A. (1966). *Musical ability in children and its measurement*. October House.

Birnbaum, M. H. (2004). Methodological and ethical issues in conducting social psychological research via the Internet. In C. Sansone, C. C. Morf, & A. T. Panter (Eds.), *Handbook of methods in social psychology* (pp. 359–382). Sage Publications, Inc.

Brito-Costa, S., Bem-Haja, P., Moisão, A., Alberty, A., Castro, F. V., & De Almeida, H. (2015). Psychometric properties of Portuguese version of Big Five Inventory (BFI). *International Journal of Developmental and Educational Psychology* [*INFAD Revista de Psicología*], *1*(2), 83–94. http://dx.doi.org/10.17060/ijodaep.2015.n2.v1.325

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of music practice: Underlying environmental and genetic influences. *Personality and Individual Differences, 74,* 133–138. https://doi.org/10.1016/j.paid.2014.10.006

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge University Press. https://doi.org/10.1017/CBO9780511571312

Casler, K., Bickel, L., & Hackett, E. (2013). Separate but equal? A comparison of participants and data gathered via Amazon's MTurk, social media, and face-to-face behavioral testing. *Computers in Psychology*, *29*(6), 2156–2160. http://dx.doi.org/10.1016/j.chb.2013.05.009

Chetverikov, A., & Upravitelev, P. (2015). Online versus offline: The Web as a medium for response time data collection. *Behavior Research Methods*, *48*(3), 1086–1099. https://doi.org/10.3758/s13428-015-0632-x

Chierchia, G., Fuhrmann, D., Knoll, L. J., Pi-Sunyer, B. P., Sakhardande, A. L., & Blakemore, S. (2019). The matrix reasoning item bank (MaRs-IB): Novel, open-access abstract reasoning items for adolescents and adults. *Royal Society Open Science*, *6*(10), Article 190232. https://doi.org/10.1098/rsos.190232

Cooper, P. K. (2019). It's all in your head: A meta-analysis on the effects of music training on cognitive measures in schoolchildren. *International Journal of Music Education*, *38*(3), 321–336. https://doi.org/10.1177/0255761419881495

Correia, A. I., Castro, S. L., MacGregor, C., Müllensiefen, D., Schellenberg, E. G., & Lima, C. F. (2020). Enhanced recognition of vocal emotions in individuals with naturally good musical abilities. *Emotion.* Advance online publication. http://dx.doi.org/10.1037/emo0000770

Corrigall, K. A., & Schellenberg, E. G. (2015). Predicting who takes music lessons: Parent and child characteristics. *Frontiers in Psychology*, *6*, Article 282. https://doi.org/10.3389/fpsyg.2015.00282

Corrigall, K. A., Schellenberg, E. G., & Misura, N. A. (2013). Music training, cognition, and personality. *Frontiers in Psychology*, *4*, Article 222. https://doi.org/10.3389/fpsyg.2013.00222

Dandurand, F., Bowen, M., & Shultz, T. R. (2004). Learning by imitation, reinforcement and verbal rules in problem-solving tasks. In J. Triesch & T. Jebara (Eds.). *Proceedings of the 2004 International Conference on Development and Learning* (pp. 88–95). UCSD Institute for Neural Computation.

Dandurand, F., Shultz, T. R., & Onishi, K. H. (2008). Comparing online and lab methods in a problem-solving experiment. *Behavior Research Methods*, *40*(2), 428–434. https://doi.org/10.3758/brm.40.2.428

Decker, J. H., Otto, A. R., Daw, N. D., & Hartley, C. A. (2016). From creatures of habit to goal-directed learners. *Psychological Science*, *27*(6), 848–858. https://doi.org/10.1177/0956797616639301

Fujii, S., & Schlaug, G. (2013) The Harvard Beat Assessment Test (H-BAT): A battery for assessing beat perception and production and their dissociation. *Frontiers in Human Neuroscience, 7:*771. https://doi.org/10.3389/fnhum.2013.00771

Gordon, E. (1965). *Musical aptitude profile: Manual*. Houghton Mifflin.

Gosling, S. D., & Mason, W. (2015). Internet research in psychology. *Annual Review of Psychology*, *66*(1), 877–902. https://doi.org/10.1146/annurev-psych-010814-015321

Gosling, S. D., Vazire, S., Srivastava, S., & John, O. (2004). Should we trust web-based studies? A comparative analysis of six preconceptions about Internet questionnaires. *American Psychologist*, *59*(2), 93–104. https://doi.org/10.1037/0003-066x.59.2.93

Greenberg, D. M., Müllensiefen, D., Lamb, M. E., & Rentfrow, P. J. (2015). Personality predicts musical sophistication. *Journal of Research in Personality, 58*, 154–158. http://dx.doi.org/10.1016/j.jrp.2015.06.002

Grootswagers, T. (2020). A primer on running human behavioural experiments online. *Behavior Research Methods*, *52*(6), 2283–2286. https://doi.org/10.3758/s13428-020-01395-3

Hartshorne, J. K., & Germine, L. T. (2015). When does cognitive functioning peak? The asynchronous rise and fall of different cognitive abilities across the life span. *Psychological science*, *26*(4), 433–443. https://doi.org/10.1177/0956797614567339

Houben, K., & Wiers, R. W. (2008). Measuring implicit alcohol associations via the Internet: Validation of Web-based implicit association tests. *Behavior Research Methods*, *40*(4), 1134–1143. https://doi.org/10.3758/brm.40.4.1134

Ilari, B. S., Keller, P., Damasio, H., & Habibi, A. (2016). The development of musical skills of underprivileged children over the course of 1 year: A study in the context of an El Sistema-inspired program. *Frontiers in Psychology, 7*:62. https://doi.org/10.3389/fpsyg.2016.00062

Jarosz, A., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting Bayes factors. *Journal of Problem Solving, 7*(1), 2–9. http://dx.doi.org/10.7771/1932-6246.1167

JASP Team. (2020). *JASP* (Version 0.14.1) [Computer software]. https://jasp-stats.org/

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford University Press.

John, O. P., & Srivastava, S. (1999). The Big Five trait taxonomy: History, measurement, and theoretical perspectives. In L. A. Pervin & O. P. John (Eds.), *Handbook of personality: Theory and research* (pp. 102–138). Guilford Press.

Kragness, H. E., Swaminathan, S., Cirelli, L. K., & Schellenberg, E. G. (2021). Individual differences in musical ability are stable over time in childhood. *Developmental Science*. Advance online publication. https://doi.org/10.1111/desc.13081

Krantz, J. H., & Dalal, R. (2000). Validity of Web-based psychological research. In M. H. Birnbaum (Ed.), *Psychological experiments on the Internet* (pp. 35–60). Academic Press.

Kuckelkorn, K., de Manzano, Ö., & Ullén, F. (2021). Musical expertise and personality—differences related to occupational choice and instrument categories. *Personality and Individual Differences*, *173*, Article 110573. https://doi.org/10.1016/j.paid.2020.110573

Law, L. N. C., & Zentner, M. (2012). Assessing musical abilities objectively: Construction and validation of the Profile of Music Perception Skills. *PLoS ONE*, *7*(12), Article e52508. https://doi.org/10.1371/journal.pone.0052508

Lima, C. F., & Castro, S. L. (2011). Speaking to the trained ear: Musical expertise enhances the recognition of emotions in speech prosody. *Emotion*, *11*(5), 1021–1031. https://doi.org/10.1037/a0024521

Lima, C. F., Correia, A. I., Müllensiefen, D., & Castro, S. L. (2020). Goldsmiths Musical Sophistication Index (Gold-MSI): Portuguese version and associations with socio-demographic factors, personality and music preferences. *Psychology of Music*, *48*(3), 376–388. https://doi.org/10.1177/0305735618801997

McCrae, R. R., & Costa, P. T. (1987). Validation of the five-factor model of personality across instruments and observers. *Journal of Personality and Social Psychology, 52*(1), 81–90. https://doi.org/10.1037/0022-3514.52.1.81

McCrae, R. R., & Greenberg, D. M. (2014). Openness to experience. In D. K. Simonton (Ed.), *Handbook of genius* (pp. 222–243). Wiley-Blackwell

McCrae, R. R., & John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of Personality, 60*(2), 175–215. https://doi.org/10.1111/j.1467-6494.1992.tb00970.x

Milne, A. E., Bianco, R., Poole, K. C., Zhao, S., Oxenham, A. J., Billig, A. J., & Chait, M. (2020). An online headphone screening test based on dichotic pitch. *Behavior Research Methods*. Advance online publication. https://doi.org/10.3758/s13428-020-01514-0

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425–1433. https://doi.org/10.1177/0956797611416999

Mrazek, M. D., Phillips, D. T., Franklin, M. S., Broadway, J. M., & Schooler, J. W. (2013). Young and restless: validation of the Mind-Wandering Questionnaire (MWQ) reveals disruptive impact of mind-wandering for youth. *Frontiers in Psychology*, *4*, Article 560. https://doi.org/10.3389/fpsyg.2013.00560

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE*, *9*(2), Article e89642. https://doi.org/10.1371/journal.pone.0089642

Nussenbaum, K., Scheuplein, M., Phaneuf, C. M., Evans, M. D., & Hartley, C. A. (2020). Moving developmental research online: Comparing in-lab and web-based studies of model-based reinforcement learning. *Collabra: Psychology*, *6*(1), Article 17213. https://doi.org/10.1525/collabra.17213

Penhune, V. B. (2019). Musical expertise and brain structure: The causes and consequences of training. In M. H. Thaut & D. A. Hedges, (Eds.), *The Oxford handbook of music and the brain* (pp. 417–438). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198804123.013.17

Penhune, V. B. (2020). A gene-maturation-environment model for understanding sensitive period effects in musical training. *Current Opinion in Behavioral Sciences*, *36*, 13–22. https://doi.org/10.1016/j.cobeha.2020.05.011

Penhune, V. B., & de Villers-Sidani, E. (2014). Time for new thinking about sensitive periods. *Frontiers in Systems Neuroscience*, *8*, Article 55. https://doi.org/10.3389/fnsys.2014.00055

Peretz, I., Champod, A. S., & Hyde, K. (2003). Varieties of musical disorders. *Annals of the New York Academy of Sciences, 999*, 58– 75. https://doi.org/10.1196/annals.1284.006

Peretz, I., Gosselin, N., Nan, Y., Caron-Caplette, E., Trehub, S. E., & Béland, R. (2013). A novel tool for evaluating children's musical abilities across age and culture. *Frontiers in Systems Neuroscience, 7*:30. https://doi.org/ 10.3389/fnsys.2013.00030

Raven, J. C. (1965). *Advanced Progressive Matrices, Sets I and II*. Psychological Corporation.

Smith, M. A., & Leigh, B. (1997). Virtual subjects: Using the Internet as an alternative source of subjects and research environment. *Behavior Research Methods, Instruments, & Computers*, *29*(4), 496–505. https://doi.org/10.3758/bf03210601

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology*, *98*(2), 457–468. https://doi.org/10.1037/0022-0663.98.2.457

Schellenberg, E. G. (2011). Music lessons, emotional intelligence, and IQ. *Music Perception*, *29*(2), 185–194. https://doi.org/10.1525/mp.2011.29.2.185

Schellenberg, E. G., & Mankarious, M. (2012). Music training and emotion comprehension in childhood. *Emotion*, *12*(5), 887–891. https://doi.org/10.1037/a0027971

Schellenberg, E. G., & Moreno, S. (2010). Music lessons, pitch processing, and g. *Psychology of Music*, *38*(2), 209–221. https://doi.org/10.1177/0305735609339473

Schaal, N. K., Banissy, M. J., & Lange, K. (2015). The rhythm span task: Comparing memory capacity for musical rhythms in musicians and non-musicians. *Journal of New Music Research, 44*(1), 3–10. https://doi.org/10.1080/09298215.2014.937724

Seashore, C. (1919). *The psychology of musical talent*. New York, NY: Holt.

Seashore, C. E., Saetveit, J. G., & Lewis, D. (1960). *The Seashore measures of musical talent* (rev. ed.). Psychological Corporation.

Swaminathan, S., Kragness, H. E., & Schellenberg, E. G. (2021). The Musical Ear Test: Norms and correlates from a large sample of Canadian undergraduates. *Behavior Research Methods*. Advance online publication. https://doi.org/10.3758/s13428-020-01528-8

Swaminathan, S., & Schellenberg, E. G. (2020). Musical ability, music training, and language ability in childhood. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *46*(12), 2340–2348. https://doi.org/10.1037/xlm0000798

Swaminathan, S., & Schellenberg, E. G. (2017). Musical competence and phoneme perception in a foreign language. *Psychonomic Bulletin & Review*, *24*(6), 1929–1934. https://doi.org/10.3758/s13423-017-1244-5

Swaminathan, S., & Schellenberg, E. G. (2018). Musical competence is predicted by music training, cognitive abilities, and personality. *Scientific Reports*, *8*(1), Article 9223. https://doi.org/10.1038/s41598-018-27571-2

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude? *Intelligence*, *62*, 119–124. https://doi.org/10.1016/j.intell.2017.03.005

Swaminathan, S., Schellenberg, E. G., & Venkatesan, K. (2018). Explaining the association between music training and reading in adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*(6), 992–999. https://doi.org/10.1037/xlm0000493

Taherbhai, H., Seo, D., & Bowman, T. (2012). Comparison of paper–pencil and online performances of students with learning disabilities. *British Educational Research Journal*, *38*(1), 61–74. https://doi.org/10.1080/01411926.2010.526193

Thomas, K. S., Silvia, P. J., Nusbaum, E. C., Beaty, R. E., & Hodges, D. A. (2016). Openness to experience and auditory discrimination ability in music: An investment approach. *Psychology of Music, 44*(4), 792–801. https://doi.org/10.1177/0305735615592013

Ubbiali, A., Chiorri, C., Hampton, P., & Donati, D. (2013). Italian Big Five Inventory. Psychometric properties of the Italian adaptation of the Big Five Inventory (BFI). *Bollettino di Psicologia Applicata, 266*(59), 37–48.

Ullén, F., Mosing, M. A., Holm, L., Eriksson, H., & Madison, G. (2014). Psychometric properties and heritability of a new online test for musicality, the Swedish Musical Discrimination Test. *Personality and Individual Differences, 63*, 87–93. http://dx.doi.org/10.1016/j.paid.2014.01.057

Wagenmakers, E., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E.-J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., de Jong, T., van den Bergh, D., Sarafoglou, A., Steingroever, H., Derks, K., Rouder, J. N., & Morey, R. D. (2017). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review, 25*(1), 58–76. https://doi.org/10.3758/s13423-017-1323-7

Wagenmakers, E., Verhagen, J., & Ly, A. (2016). How to quantify the evidence for the absence of a correlation. *Behavior Research Methods, 48*(2), 413–426. https://doi.org/10.3758/s13428-015-0593-0

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010a). The Musical Ear Test, a new reliable test for measuring musical competence. *Learning and Individual Differences*, *20*(3), 188–196. https://doi.org/10.1016/j.lindif.2010.02.004

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010b). Corrigendum to “The Musical Ear Test, a new reliable test for measuring musical competence” [Learning and Individual Differences Volume 20 (3) (2010) 188–196]. *Learning and Individual Differences, 20*(6), 705. 10.1016/j.lindif.2010.10.001

Wang, X., Ossher, L., & Reuter-Lorenz, P. A. (2015). Examining the relationship between skilled music training and attention. *Consciousness and Cognition*, *36*, 169–179. https://doi.org/10.1016/j.concog.2015.06.014

Wing, H. D. (1962). A revision of the Wing Musical Aptitude Test. *Journal of Research in Music Education, 10*(1), 39–46. https://doi.org/10.2307/3343909

Woods, K. J. P., Siegel, M. H., Traer, J., & McDermott, J. H. (2017). Headphone screening to facilitate web-based auditory experiments. *Attention, Perception, & Psychophysics*, *79*(7), 2064–2072. https://doi.org/10.3758/s13414-017-1361-2

Zentner, M., & Strauss, H. (2017). Assessing musical ability quickly and objectively: development and validation of the Short-PROMS and the Mini-PROMS. *Annals of the New York Academy of Sciences*, *1400*(1), 33–45. https://doi.org/10.1111/nyas.13410

CHAPTER 4

Associations Between Music Training and Cognitive Abilities: The Special Case of Professional Musicians

Vincenzi, M.*, Correia, A. I.*, Vanzella, P., Pinheiro, A. P., Lima, C. F.*, & Schellenberg, E. G.* (2022). Associations between music training and cognitive abilities: The special case of professional musicians. *Psychology of Aesthetics, Creativity, and the Arts*. Advance online publication. http://dx.doi.org/10.1037/aca0000481

* Joint first/last authors

Abstract

We sought to clarify the commonly accepted link between music training and cognitive ability. Professional musicians, non-professionals with music training, and musically untrained individuals ($N = 642$) completed measures of musical ability, personality, and general cognitive ability. Professional musicians scored highest on objective and self-report measures of musical ability. On personality measures, professional musicians and musically trained participants scored similarly but higher than untrained participants on agreeableness, openness-to-experience, and the personality metatrait *stability*. The professionals scored higher than the other two groups on extraversion and the metatrait *engagement*. On cognitive ability, however, they were indistinguishable from untrained participants. Instead, musically trained non-professionals exhibited the highest cognitive ability. In short, professional musicians differed from other individuals in musical ability and personality, but not in cognitive ability. We conclude that music training predicts higher cognitive ability only among individuals who do not become professional musicians, and offer possible explanations.

Keywords: music, training, cognition, personality, learning

4.1. Introduction

Over the past few decades, a growing number of studies have tried to elucidate whether music training improves nonmusical cognitive abilities. Although music training has positive associations with general, visuospatial, and language abilities (see Swaminathan & Schellenberg, 2019 for a review), most of the relevant evidence comes from correlational designs (Schellenberg, 2020), which preclude inferences of causation. The issue is further complicated because music training is associated with demographic, personality, and cognitive variables during childhood, when training typically occurs, as well as in adulthood after training has stopped (Corrigall et al., 2013). Moreover, evidence from twin studies documents a genetic component to musical achievement (Hambrick & Tucker-Drob, 2015), musical ability (Mosing et al., 2014), choice of musical instrument and genre (Mosing & Ullén, 2018), practicing music (Hambrick & Tucker-Drob, 2015; Mosing et al., 2014), and the link between musical ability and general cognitive ability (Mosing et al., 2016). These pre-existing and extraneous individual differences in musical and nonmusical variables ensure that musically trained individuals are a poor model for the study of transfer or plasticity, despite claims to the contrary (e.g., Steele & Zatorre, 2018).

In the present investigation, our primary focus was on individuals with the highest levels of musical experience—professional musicians. The available literature typically fails to distinguish professional musicians, whose daily behaviors revolve around music, from musically trained individuals who ultimately become construction workers, chefs, doctors, and so on. Here we defined (1) professional musicians as those whose careers involve music instruction (e.g., music professors) or performance (e.g., members of orchestras), or full-time study at the tertiary level or higher, and (2) musically trained individuals as those who had at least 6 years of lessons and were not working as musicians.

Although the "6-year rule" represents a general consensus in the literature as a threshold for musical expertise (Zhang et al., 2020), it typically ignores whether individuals are working as musicians. This issue is particularly important because of findings showing that music training, when treated as a continuous variable (i.e., duration of formal lessons), has a positive linear association with general cognitive ability in childhood *and* in adulthood (e.g., Corrigall et al., 2013; Degé et al., 2011; Swaminathan et al., 2017). One might logically predict, therefore, that individuals with the highest levels of experience—professional musicians—tend to be intellectually gifted, which seems unlikely. The primary goal of the present investigation was to test our hypotheses that professional musicians are different from musically trained individuals in musical ability and personality traits, but not in cognitive abilities.

Whereas the hypothesis about musical ability is self-explanatory, the hypothesis about cognitive abilities stemmed from evidence that associations between music training and cognitive ability tend to be strongest among middle-class children, very few of whom become professional musicians. For example, 9- to 12-year-olds with at least 2 years of music lessons can have IQs that are 10 points (2/3 of 1 *SD*) higher than their counterparts with no lessons (Schellenberg, 2011). At 7 and 8 years of age, children with 1 year of lessons sometimes exceed their untrained counterparts by 15 points (1 *SD*; Schellenberg & Mankarious, 2012). Associations of such large magnitude preclude a causal role for the training, and suggest instead that high-functioning children are more likely than other children to take music lessons. In any event, preliminary evidence indicates that the link between music training and cognitive ability breaks down when actual musicians are studied. For example, when German university students from nonmusical disciplines (law, physics, psychology) were compared to young adults who played in a symphony orchestra or studied music at the post-graduate level, the musicians had *lower* IQ scores (Brandler & Rammsayer, 2003). In another instance, general cognitive ability did not differ between German university music students and students from other disciplines matched for age and education (Helmbold et al., 2005).

Our hypothesis about personality traits was motivated by evidence that personality predicts occupational choices (Holland, 1997). One personality trait from the Big Five model, openness-to-experience (hereafter *openness*), is associated positively with creativity across domains (Feist, 1998, 2019). Openness also predicts musical behaviors and skills (e.g., Corrigall et al., 2013; Lima et al., 2020), and lifetime amount of music practice (Butkovic et al., 2015). Extraversion is another personality trait that predicts creativity, but not as strongly as openness (Feist, 2019). Because the Big Five traits are intercorrelated, metatraits (higher-order personality factors) have been proposed (DeYoung, 2006). Shared variance between openness and extraversion forms one metatrait that indexes behavioral *engagement*,[4] linked theoretically to the neurotransmitter dopamine (DeYoung, 2013); shared variance among agreeableness, conscientiousness, and neuroticism forms a second metatrait indexing *stability*, linked to serotonin (Hirsh et al., 2009). Because engagement is an aggregate of extraversion *and* openness, it has a strong positive association with creativity (Feist, 2019), which extends to

[4] We avoid standard terminology (*plasticity*) because of potential confusion with neural and behavioral changes that occur as a consequence of experience.

objectively measured creative achievements and everyday creative behaviors, including music (Sylvia et al., 2009).

In a previous study, Kuckelkorn et al. (2021) compared the personalities of professional musicians to those of amateur musicians and nonmusicians. Professional musicians had higher levels of openness than amateurs, who had higher levels than nonmusicians, as one might expect, although neuroticism unexpectedly showed the same pattern. The other main finding was that, in both musician groups, singers were more extraverted than instrumentalists, except for percussionists. One problematic aspect of this study was that amateur musicians were classified as individuals who had played a musical instrument (including voice) at *any* point in their lives for *any* amount of time but were not professionally active. In other words, professional and amateur musicians differed markedly in music training as well as professional status, which makes these response patterns difficult to interpret.

In the present study, we examined group differences in musical ability, personality, and general cognitive ability in a sample that comprised professional musicians and participants who were musically trained or untrained. We expected to find robust group differences in measures of musical ability (professionals > trained > untrained). For personality, previous findings allowed us to be relatively confident that the professional and trained groups would score higher than the untrained group on openness and extraversion, and on engagement more generally. We also expected that professional musicians would have particularly high scores on these personality variables. Finally, although musically trained participants should perform better than untrained participants on a measure of general cognitive ability, we did not expect the professionals to outperform the trained group.

4.2. Method

4.2.1. Participants

The study was approved by the local ethics committee at Iscte-University Institute of Lisbon (reference 07/2021). All participants provided informed consent. The sample comprised 642 volunteer participants, who ranged in age from 18 to 84 years (M = 34.8, SD = 15.1; 384 women, 258 men). They were recruited primarily through social-media postings for an online study on personality and musical abilities, which was open to individuals with any level of musical expertise. To increase the study's appeal, the posting specified that participants would receive feedback about their musical ability and personality. Two of the authors (M.V., P.V.), who are professional musicians, contacted other musicians directly, primarily through social media, asking them to participate and to inform other musicians about the study. The study was made available in four languages (Italian: *n* = 290, European Portuguese: *n* = 151, Brazilian Portuguese: *n* = 150, and English: *n* = 51), which reflected the make-up of the research team while maximizing sample size and diversity.

The sample was restricted to respondents who fell into one of three groups: professional musicians, musically trained participants who were not professionals, and musically untrained participants. Professional musicians (*n* = 176) had a music-related job and/or were enrolled as students in a university-level music program. Trained participants (*n* = 121) had at least 6 years of music lessons but did not meet the criteria for professionals. Thus, this group included many amateur musicians. Finally, untrained participants (*n* = 345) had a maximum of 2 years of music training. An additional 118 participants with 3-5 years of music lessons were tested but excluded because they could not be identified clearly as trained or untrained. Five other participants were tested but excluded from analyses because of self-reported poor hearing ability (*n* = 1) or unspecified gender (*n* = 4).

Table 4.1. Primary Instrument Category for Musically Trained Participants and Professional Musicians

	Musically Trained	Professional Musicians
Bowed	8	33
Brass	5	3
Keyboard	49	78
Percussion	2	3
Plucked	14	13
Voice	26	16
Woodwind	11	25
Others	1	2
No Response	5	3
Total	121	176

Professional musicians were employed as music professors (*n* = 126), orchestral musicians (*n* = 41), soloists (*n* = 50), conductors (*n* = 12), choristers (*n* = 8), pianists (*n* = 26), composers (*n* = 25), and members of small musical ensembles (*n* = 67), but these categories were not mutually exclusive. The most common primary instrument was piano/keyboard, both for professional musicians (44%) and trained participants (40%). Table 4.1 provides details separately for professional musicians and trained participants, using standard instrument categories (voice, woodwind, etc.). When asked about the genre of music they performed (or had performed) most regularly, a majority played classical music in both groups (professionals: 88.9%; trained:

74.8%). The next most common genre was pop music (professionals: 3.7%; trained: 12.2%). Some trained participants played rock music (7.8%) and some professionals played jazz (3.1%), but all other genres were played by less than 2% of participants in either group.

The online testing format and the exploratory nature of the research motivated us to test as many participants as possible. A post-hoc sensitivity analysis conducted with G* Power 3.1 (Faul et al., 2007) confirmed that a sample of 642 participants had 80% power to detect small associations of at least $.01 \leq \eta^2 \leq .02$ (Analysis of Covariance, three covariates, alpha = .05).

4.2.2. Materials and Tasks

All tasks and questionnaires were adapted for Gorilla Experiment Builder (Anwyl-Irvine et al., 2018), a widely used and flexible platform for online behavioral research. Each measure in the testing protocol was created originally in English. Whenever available, published translations were used for the European Portuguese, Brazilian Portuguese, and Italian versions of the tests. Otherwise, *ad hoc* translations were created by native speakers who were also fluent in English. Correia et al. (2021) documented that the online versions and translations of all tests used in the present study had good reliability and validity, matching that of in-person testing conducted in English (Swaminathan et al., 2021), and that performance did not vary as a function of testing language.

4.2.2.1. Questionnaires

Goldsmiths Musical Sophistication Index (Gold-MSI). The Gold-MSI (Müllensiefen et al., 2014; Lima et al., 2020) is a 38-item self-report questionnaire evaluating different aspects of musical behaviors and abilities. Responses to each item are made on 7-point rating scales. Scores on different subsets of items are averaged to form five subscales: Active Engagement (e.g., *I often read or search the internet for things related to music*), Perceptual Abilities (e.g., *I am able to judge whether someone is a good singer or n*ot), Music Training (e.g., *I would not consider myself a musician*), Singing Abilities (e.g., *If somebody starts singing a song I don't know, I can usually join in*), and Emotions (e.g., *I sometimes choose music that can trigger shivers down my spine*). A General Musical Sophistication factor is also formed, averaged from 18 items representative of the five subscales. The Music Training subscale is notable for considering—in addition to lifetime duration of music lessons and regular practice—music theory, number of musical instruments, peak amount of practice, perceived status as a musician, and compliments on performances. Our principal interest was in the subscales that measured music training and musical abilities (i.e., Music Training, Perceptual Ability, Singing Ability).

Big-Five Inventory (BFI). The BFI (John & Srivastava, 1999) is a widely used self-report questionnaire that includes 44 items, which measure the traits from the five-factor model of personality (McCrae & John, 1992): Openness-to-Experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism. Participants rate how well each item describes them on a 5-point rating scale. The five personality traits are calculated as mean scores. Metatrait scores are derived by using principal-components analysis to extract the shared variance between openness and extraversion scores to form engagement scores, and the shared variance among agreeableness, conscientiousness, and neuroticism scores to form stability scores.

Mind-Wandering Questionnaire (MWQ). The MWQ (Mrazek et al., 2013) is a 5-item questionnaire measuring trait levels of mind-wandering (e.g., *I find myself listening with one ear, thinking about something else at the same time*). Participants rate their agreement with each item on a 6-point rating scale (1 = *almost never*, 6 = *almost always*). The mean serves as an index of an individual's frequency of mind-wandering.

4.2.2.2. Objective Ability Tests

Musical Ear Test (MET). The MET (Wallentin et al., 2010) is an objective measure of musical ability that has two subtests, Melody and Rhythm, presented in that order. On each of 52 trials per subtest, participants hear two short sequences of piano tones (Melody) or drumbeats (Rhythm) and judge whether they are identical. Half of the trials are *different*, such that one or more tones are displaced in the Melody subtest, and one or more inter-onset intervals are altered in the Rhythm subtest. Detailed information about the MET stimuli is provided in Swaminathan et al. (2021). Scores for both subtests are calculated as the number of correct responses.

Because the MET was administered at the end of the testing session and was relatively lengthy (approximately 20 min), some participants did not finish the test or provided incomplete data. MET Melody or Rhythm scores were also excluded for participants with more than 10 (of 52) or 5 consecutive missing responses on a subtest. Sample sizes were therefore smaller when analyses included the Melody (n = 546) or the Rhythm (n = 529) subtest.

General Cognitive Ability. General cognitive ability (hereafter cognitive ability) was tested with the Matrix Reasoning Item Bank (MaRs-IB; Chierchia et al., 2019). The MaRs-IB, which has been used successfully by a variety of independent research groups (e.g., Correia et al., 2021; Nussenbaum et al., 2020), is a freely available online measure of abstract (nonverbal) reasoning modeled after Raven's Advanced Progressive Matrices (Raven, 1965). The test has 80 trials. On each trial, a 3 x 3 matrix is presented. Eight of nine cells contain abstract shapes (varying on four dimensions: color, size, shape, and location), but the cell in the bottom-right corner is always empty. Participants' task is to choose one of four alternatives to complete the matrix, following the rules that govern differences among the other eight cells. The duration of the task is fixed at 8 min, but participants are not informed of the duration or the number of trials, only that they have up to 30 s to complete each trial. If participants complete the 80 trials in less than 8 min, the trials begin again in the same order, but responses from the second round are not considered in calculating scores, which are the proportion of responses given by the participant that are correct (excluding responses made in < 250 ms). Proportions were logit-transformed for statistical analyses.

4.2.3. Procedure

After providing informed consent, participants completed the questionnaires in the following order: MWQ, Gold-MSI, and BFI. After the questionnaires, they completed the MaRs-IB followed by the MET. At the end of the testing session, participants were provided with summary feedback about their personality, musical sophistication, and musical abilities. Ethical considerations precluded feedback about cognitive ability.

4.3. Results

We initially compared our three groups of participants in terms of basic demographic variables. Descriptive and inferential statistics are provided in Table 4.2. Analysis of Variance (ANOVA) uncovered group differences in both age and education. Follow-up pairwise comparisons (Tukey's HSD) revealed that professional musicians were older than trained and untrained participants, *p*s < .001, who did not differ, $p = .979$. Professional musicians also had more education than trained participants, $p = .032$, and untrained ones, $p < .001$, who did not differ, $p = .079$. A chi-square test of independence indicated that the gender ratio also differed across groups, with a greater proportion of males among professional musicians than among trained participants, $p < .001$, and untrained ones, $p < .001$, who did not differ, $p = .726$. Thus, age, education, and gender were included as covariates in the statistical analyses that follow. As one would expect from the available literature (Deary et al., 2007; Hartshorne & Germine, 2015; Salthouse, 2009), cognitive ability also had a small negative correlation with age, $r = -.089$, $N = 642$, $p = .023$, a positive correlation with education, $r = .190$, $N = 642$, $p < .001$, but no association with gender, $p = .165$.

Table 4.2. Descriptive and Inferential Statistics for Demographic Variables

	Musically Untrained		Musically Trained		Professional Musicians		Group Comparison	
	M	*SD*	*M*	*SD*	*M*	*SD*	$F(2, 639)$	η^2
Age	32.40	14.85	32.70	14.18	40.94	14.48	21.39	.063
Education	3.98	1.05	4.21	1.04	4.52	0.92	16.24	.048
	M/F	%M	M/F	%M	M/F	%M	$\chi^2(2)$	ϕ
Gender	123/222	35.6	41/80	33.9	94/82	53.4	17.75	.166

Note: All *p*s < .001

Analysis of Covariance (ANCOVA) confirmed that our three groups of participants differed on each of the music variables. Descriptive and inferential statistics are provided in Table 4.3 and illustrated in Figure 1, with variables standardized for comparability. Follow-up comparisons (Tukey's HSD) revealed that professional musicians scored higher than musically trained participants, who scored higher than the untrained group, on the MET Melody subtest, and on the Music Training, Perceptual Abilities, and Singing Abilities subscales from the Gold-MSI, *p*s < .005. This same pattern (i.e., professionals > trained > untrained) extended to the Active Engagement subscale and the General Factor from the Gold-MSI, *p*s < .001. The professional and trained groups scored higher than untrained participants on the MET Rhythm subtest and on the Emotions subscale from the Gold-MSI, *p*s < .001, but the professional and trained groups did not differ (Rhythm: $p = .936$, Emotions, $p = .221$). In short, expected group differences in musical ability were strong, whether performance was indexed objectively or by self-reports.

Table 4.3. Descriptive and Inferential Statistics for the Musical Ear Test (MET) and the Goldsmiths Musical Sophistication Index (Gold-MSI)

	Musically Untrained		Musically Trained		Professional Musicians		Group Comparison		
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	d. f.	η^2
MET									
Melody	34.74	6.43	39.99	5.70	43.10	4.71	87.14	540	.241
Rhythm	36.71	5.71	39.46	5.08	40.30	4.46	18.65	523	.065
Gold-MSI									
Active Engagement	3.88	1.23	4.58	0.99	5.25	0.82	97.02	636	.230
Perceptual Abilities	4.94	1.07	6.03	0.69	6.38	0.55	165.58	636	.341
Music Training	2.39	1.19	5.36	0.78	6.05	0.55	923.47	636	.742
Singing Abilities	3.76	1.35	4.97	0.96	5.41	0.89	132.18	636	.292
Emotions	5.49	0.95	6.00	0.67	6.05	0.77	41.66	636	.112
General Factor	3.55	1.12	5.06	0.77	5.73	0.52	352.50	636	.521

Note: All *p*s < .001. Age, education, and gender were held constant in the group comparisons. All *F* statistics have 2 d.f. in the numerator.

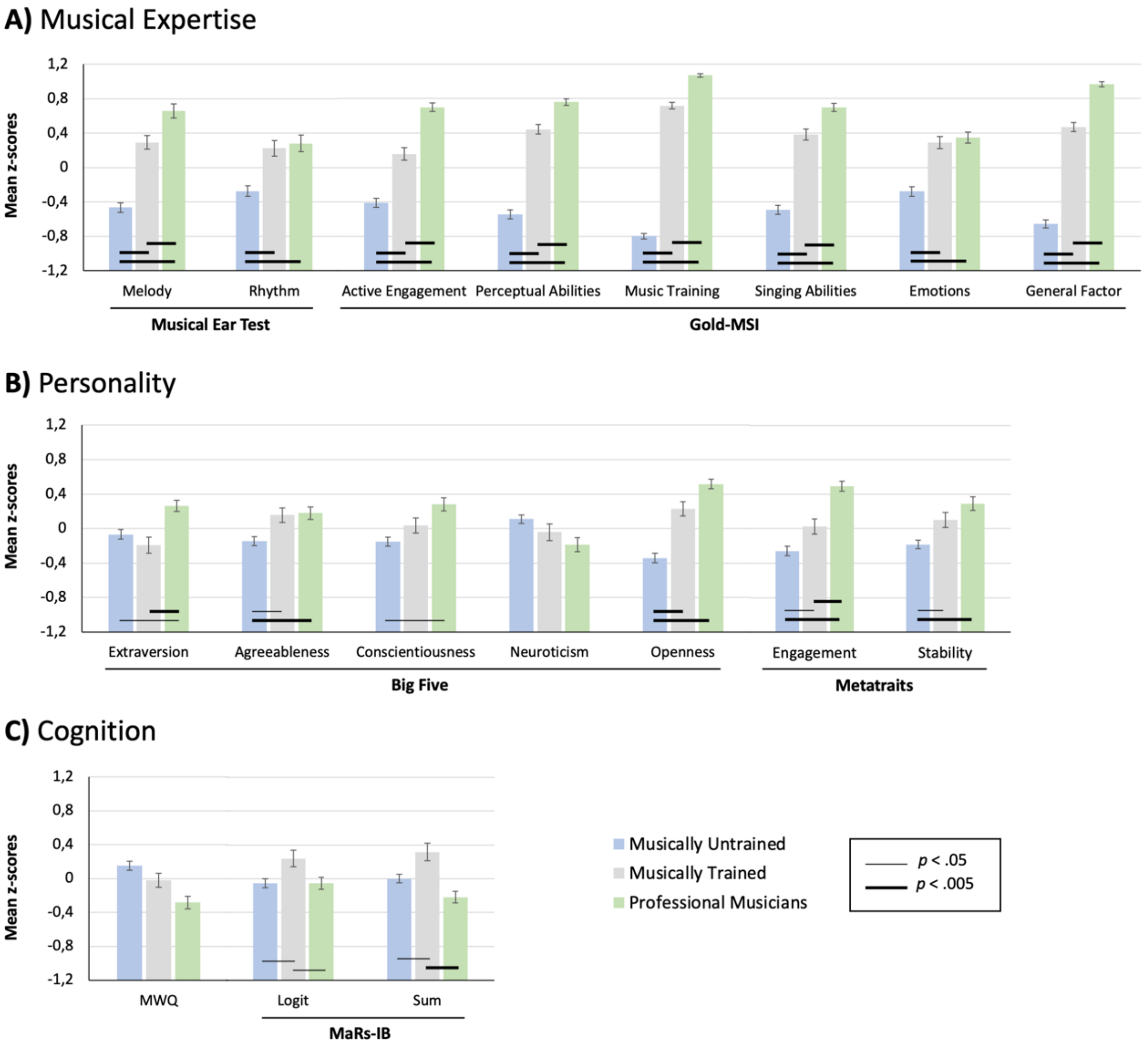

Figure 4.1. Means and standard errors for study variables, standardized for comparability. Pairwise comparisons (Tukey's HSD) were conducted after ANCOVA confirmed a significant main effect of group (covariates: age, education, and gender).

Descriptive and inferential statistics for personality variables are provided in Table 4.4 and illustrated in Figure 1. For the Big Five traits, the three groups did not differ in terms of neuroticism, but they did on the other four traits. As expected, professional musicians and trained participants had higher mean openness scores compared to untrained participants, *p*s < .001, but the professional and trained groups did not differ, $p = .132$. Agreeableness showed a similar pattern, with professionals, $p = .003$, and trained participants, $p = .013$, scoring higher than nonmusicians, but no differences between the professional and trained groups, $p = .984$. Professional musicians had higher conscientiousness scores than untrained participants, $p = .013$, but the trained participants fell in between, such that they were no different from the professional, $p = .604$, or untrained, $p = .296$, groups. Finally, professional musicians were more extraverted than trained participants, $p = .001$, and untrained participants, $p = .006$, but the trained and untrained groups did not differ, $p = .413$.

Table 4.4. Descriptive and Inferential Statistics for the Personality Variables

	Musically Untrained		Musically Trained		Professional Musicians		Group Comparison		
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η^2
Big Five									
Openness	3.80	0.59	4.14	0.54	4.31	0.43	42.83	< .001	.118
Conscientiousness	3.50	0.69	3.63	0.68	3.80	0.71	4.23	.015	.012
Extraversion	3.17	0.82	3.07	0.84	3.43	0.68	7.39	< .001	.022
Agreeableness	3.71	0.56	3.87	0.53	3.89	0.54	7.44	< .001	.022
Neuroticism	3.17	0.79	3.04	0.88	2.92	0.89	1.25	.287	.004
Metatraits									
Engagement	-.259	1.01	.023	.968	.492	.789	27.54	< .001	.078
Stability	-.183	.936	.101	.965	.290	1.07	6.83	.001	.019

Note: Age, education, and gender were held constant in the group comparisons. All *F* statistics have 2,636 d.f.

Because Kuckelhorn et al. (2021) reported that extraversion was elevated only for vocalists, we compared professional musicians and trained participants who were vocalists to other participants from these two groups. Mean levels of extraversion were slightly *lower* ($M = 3.26$) for vocalists compared to other participants ($M = 3.28$). We also compared vocalists *and* percussionists, who did not differ in Kuckelhorn et al.'s study, to other participants from the professional and trained groups. Again, mean levels of extraversion were slightly lower for the vocalists and percussionists ($M = 3.20$ vs. $M = 3.29$). Higher extraversion scores for the professionals over the trained participants also remained evident when instrument category was held constant, $F(1, 275) = 14.69$, $p < .001$, partial $\eta^2 = .051$, and there was no main effect of instrument category, $p = .469$, and no interaction between instrument category and the two groups, $p = .919$. Finally, we conducted the same statistical analyses reported by Kuckelkorn et al. and failed to replicate their results: For professional musicians, there was no effect of main-instrument category on Big Five personality traits in a Multivariate Analysis of Variance (MANOVA), $p = .314$, or on extraversion in a univariate ANOVA, $p = .397$; for musically trained participants, findings were similar (MANOVA: $p = .188$, ANOVA: $p = .892$).

For personality metatraits (Table 4.4, Figure 4.1), engagement scores were higher for professional musicians compared to trained participants, $p = .001$, and untrained ones, $p < .001$, and higher for trained than for untrained participants, $p = .019$. Stability scores were higher for professional musicians, *p* = .004, and trained participants, *p* = .021, compared to untrained participants, but the professional and trained groups did not differ, *p* = .972.

For cognitive variables, descriptive statistics and inferential statistics are provided in Table 4.5 and illustrated in Figure 4.1. The three groups did not differ in mind-wandering, but they did in general cognitive ability. As predicted, trained participants had higher scores than untrained participants, *p* = .048. Unexpectedly, trained participants also had higher scores than professional musicians, *p* = .035, who did not differ from untrained participants, *p* = .864. After adjusting for the covariates, professionals actually had the *lowest* mean. Because the professionals were older on average than the other groups, if their absolute (unadjusted) levels of performance matched that of the trained participants, this could potentially indicate higher-than-expected cognitive ability. Nevertheless, even when age was allowed to co-vary, the advantage remained evident for trained participants over professional musicians, *p* = .005, and untrained participants, *p* = .038, but the professional and untrained groups did not differ, *p* = .427.

Table 4.5. Descriptive and Inferential Statistics for the Cognitive Variables

	Musically Untrained		Musically Trained		Professional Musicians		Group Comparison		
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η^2
Mind Wandering	3.29	0.96	3.13	0.88	2.88	0.95	2.75	.064	.008
Cognitive Ability—1	.614	0.15	.654	0.15	.614	0.14	3.59	.028	.010
Cognitive Ability—2	23.3	5.64	25.1	6.73	22.0	5.31	5.90	.003	.017

Note: Cognitive Ability—1: Proportion of responses that were correct (logit transformed in analysis). Cognitive Ability—2: Sum of correct responses. Age, education, and gender were held constant in the group comparisons. All *F* statistics have 2,636 d.f.

We also considered whether the method of scoring the MaRs-IB played a role in response patterns, because it awarded the same score for (1) participants who took the maximum amount of time (30 s) for each item and were correct on 14 of 16 trials, and (2) those who completed 48 trials with 42 correct responses (i.e., proportion correct = .875 in both instances). Accordingly, we re-calculated our measure of cognitive ability as the *sum* of correct responses, which is consistent with scoring of Raven's test, whether timed (Swaminathan et al., 2017) or untimed (Carpenter et al., 1990). Response patterns did not change. There was a main effect of group, with trained participants scoring higher than untrained participants, *p* = .012, and professional musicians, *p* = .003, who did not differ, *p* = .607. In absolute terms, mean scores (adjusted and unadjusted) were lowest for the professionals.

4.4. Discussion

We examined how professional musicians and musically trained and untrained individuals differ in terms of musical ability, personality, and cognition. Compared to untrained participants, the musically trained and professional groups had higher scores on all measures of musical ability, the Big Five traits openness and agreeableness, and both personality metatraits. Being a professional musician was additionally predictive of even higher levels of musical ability, extraversion, and the metatrait engagement.

As expected, the musically trained group performed better than the untrained group on our test of cognitive ability, a finding that replicates previous results (for review see Swaminathan & Schellenberg, 2019). There was no evidence, however, of enhanced cognitive abilities among professional musicians, who scored significantly *lower* than trained participants, and no different from the untrained group. How interpretable is this novel finding? Our large sample size makes it unlikely that statistical power played a role. It seems implausible, moreover, that professionals would *exceed* the trained participants in attempts to replicate our findings directly. This result is inconsistent with proposals that learning and performing music play a causal role in determining nonmusical cognitive abilities (e.g., Patel, 2011; Tierney & Kraus, 2013). Indeed, such hypotheses of far transfer and plasticity remain contentious (e.g., Sala & Gobet, 2020; Degé, 2021). As one example, Jäncke (2009) speculated that "when learning to play a musical instrument, the trainee also practices attention, planning functions, memory, and self-discipline. It is thus hypothesized that musical experience would positively influence executive functions, language functions, or even intelligence in general." If this hypothesis were true, such effects might reach a plateau at some point, but they would be unlikely to go in reverse.

Nevertheless, our test of general cognitive ability was a single, brief test of abstract reasoning, even though general cognitive ability (*g*) is best measured as a latent variable extracted from a battery of tests that cover a wide range of abilities (Carroll, 1993). Clearly, a large battery of tests was unfeasible with our online testing context, such that our choice to administer the MaRs-IB was motivated primarily by practical reasons. As noted, however, the MaRs-IB is modeled after Raven's Advanced Progressive Matrices (Raven, 1965), which measures "the ability to induce abstract relations and the ability to dynamically manage a large set of problem-solving goals in working memory" (Carpenter et al., 1983, p. 404). Such abilities are considered central to virtually all concepts of intelligence, even those that attempt to expand its definition beyond "book smarts" (Sternberg, 1985). Indeed, matrix-reasoning tests are sometimes considered to be the best single-test proxy for *g* (e.g., Deary & Smith, 2004). Even when full-scale IQ is estimated from only two tests, as in the Wechsler Abbreviated Scale of Intelligence (Wechsler, 2011), one is a test of matrix reasoning. In short, although a clear limitation of the present study is that the results (re: cognitive ability) could be test-specific, or specific to tests of matrix reasoning, our choice of test was defensible, perhaps even optimal, in light of the testing context.

Our finding of elevated engagement and extraversion for professional musicians, but not for musically trained participants, seems intuitive because most professional musicians perform music publicly, at least at some point in their lives. Additionally, most of our professionals were music professors in addition to instrumentalists (≈72% in our sample), and education is in essence a social process. Engagement and extraversion have also been associated previously with creative behaviors, including music (Feist, 2019; Sylvia et al., 2009). Our results differ from those of Kuckelkorn et al. (2021), however, who documented high levels of extraversion among some subgroups of professional musicians (vocalists), but not others. In the current study, we found evidence of a more general effect, with group differences in engagement and extraversion being independent of instrument category. Our subgroups of participants per category were small (e.g., 16 professional vocalists), though, because we did not set out to explore instrument effects. Future research could explore the possibility of such effects in greater detail.

Although our results showed that professional musicians differ from other individuals primarily in terms of musical abilities and personality, there is no doubt that some musicians are very intelligent. For example, Miles (1926) used biographical information to estimate Mozart's IQ as between 150 and 155. Brian May, the guitar player for Queen (and composer of *We Will Rock You*), is another example. May earned a PhD in astrophysics, collaborated with NASA, served as chancellor of Liverpool John Moores University, and has an asteroid named after him. IQ is also associated positively with eminence as a musician or composer, as it is across professions, although personality factors are as important as cognitive ability in predicting high levels of achievement (Miles, 1926; Simonton, 2006, 2009). The *average* professional musician, however, appears to differ from the general population primarily in terms of personality and musical ability rather than cognitive ability.

We propose that individual differences in musical ability, personality, and cognitive ability, in combination with contextual factors (e.g., socio-economic status), jointly influence developmental trajectories of musical experience. Crucially, however, they contribute differently in predicting (1) who takes music lessons and for how long, and (2) who becomes a professional musician. During the childhood and teenage years, those who have high levels of musical ability, openness-to-experience, and cognitive ability, would tend to take music lessons for the longest duration (Corrigall et al., 2013; Kragness et al., 2021). Individuals with lower levels on one these dimensions would be more likely to discontinue training or never begin, while those with lower levels on two (or three) dimensions would be even more likely to discontinue, probably at an earlier date. In early adulthood, most high-functioning individuals would opt to enter non-music professions because of personal interests, practical reasons (e.g., obtaining a well-paying job), or because of sub-optimal levels of musical ability and/or personality characteristics. Other individuals, with high levels of musical ability and engagement (openness *and* extraversion), would be the most likely to choose a career in music. In some instances, individuals with high levels of musical ability, cognitive ability, *and* engagement might also pursue music further, or enter nonmusical professions while maintaining their involvement in music. These proposals represent testable hypotheses that could be addressed in future developmental, longitudinal, and correlational studies.

Although our emphasis is on self-selection, which has typically been overlooked (Schellenberg, 2020), the environments people seek out undoubtedly influence who they become (Sauce & Matzel, 2018). In the case of skilled musical performance, the role of practice is incontrovertible. For objective measures of musical ability, however, music training plays a negligible role (Kragness et al, 2021). For cognitive ability and personality, shared environmental effects also appear to be small. Although the environment explains approximately half of the variance, these effects stem primarily from individual (non-shared) experiences (Harris, 2006).

In sum, our findings document important differences between professional musicians and nonprofessional but musically trained individuals. These differences need to be considered carefully when interpreting the results of published research, and when designing future studies.

References

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods, 52*(1), 388–407. https://doi.org/10.3758/s13428-019-01237-x

Brandler, S., & Rammsayer, T. H. (2003). Differences in mental abilities between musicians and non-musicians. *Psychology of Music, 31*(2), 123–128. https://doi.org/10.1177/0305735603031002290

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of music practice: Underlying environmental and genetic influences. *Personality and Individual Differences, 74*, 133–138. https://doi.org/10.1016/j.paid.2014.10.006

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices Test. *Psychological Review, 97*(3), 404–431. https://doi.org/10.1037/0033-295X.97.3.404

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge University Press. https://doi.org/10.1017/CBO9780511571312

Chierchia, G., Fuhrmann, D., Knoll, L. J., Pi-Sunyer, B. P., Sakhardande, A. L., & Blakemore, S. (2019). The matrix reasoning item bank (MaRs-IB): Novel, open-access abstract reasoning items for adolescents and adults. *Royal Society Open Science, 6*(10), Article 190232. https://doi.org/10.1098/rsos.190232

Correia, A. I., Vincenzi, M., Vanzella, P., Pinheiro, A., Lima, C. F., & Schellenberg, E. G. (2021). Can musical ability be tested online? Manuscript accepted for publication. *Behavior Research Methods.*

Corrigall, K. A., Schellenberg, E. G., & Misura, N. M. (2013). Music training, cognition, and personality. *Frontiers in Psychology, 4*: 222. https://doi.org/10.3389/fpsyg.2013.00222

Deary, I. J., & Smith, P. (2004). Intelligence research and assessment in the United Kingdom. In R. J. Sternberg (Ed.), *International handbook of intelligence* (pp. 1–48). Cambridge University Press. https://doi.org/10.1017/CBO9780511616648.002

Deary, I., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence, 35*, 13-21. https://doi.org/10.1016/j.intell.2006.02.001

Degé, F. (2021). Music lessons and cognitive abilities in children: How far transfer could be possible. *Frontiers in Psychology, 11*: 557807. https://doi.org/10.3389/fpsyg.2020.557807

Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: A relation mediated by executive functions. *Music Perception, 29*(2), 195–201. https://doi.org/10.1525/mp.2011.29.2.195

DeYoung, C. G. (2006). Higher-order factors of the Big Five in a multi-informant sample. *Journal of Personality and Social Psychology, 91*(6), 1138–1151. https://doi.org/10.1037/0022-3514.91.6.1138

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods 39*(2)*,* 175–191. https://doi.org/10.3758/BF03193146

Feist, G. J. (1998). A meta-analysis of personality in scientific and artistic creativity. *Personality and Social Psychology Review, 2*(4), 290–309. https://doi.org/10.1207/s15327957pspr0204_5

Feist, G. J. (2019). Creativity and the Big Two model of personality: Plasticity and stability. *Current Opinion in Behavioral Sciences, 27*, 31–35. https://doi.org/10.1016/j.cobeha.2018.07.005

Hambrick, D. Z., & Tucker-Drob, E. M. (2015). The genetics of music accomplishment: Evidence for gene–environment correlation and interaction. *Psychonomic Bulletin & Review, 22*(1), 112–120. https:// doi.org/10.3758/s13423-014-0671-9

Harris, J. R. (2006). *No two alike: Human nature and human individuality*. Norton.

Hartshorne, J. K., & Germine, L. T. (2015). When does cognitive functioning peak? The asynchronous rise and fall of different cognitive abilities across the life span. *Psychological Science, 26*(4), 433-443. https://doi.org/10.1177/0956797614567339

Helmbold, N., Rammsayer, T., & Altenmüller, E. (2005). Differences in primary mental abilities between musicians and non-musicians. *Journal of Individual Differences, 26*(2), 74–85. https://doi.org/10.1027/1614-0001.26.2.74

Hirsh, J. B., DeYoung, C. G., & Peterson, J. B. (2009). Metatraits of the Big Five differentially predict engagement and restraint of behavior. *Journal of Personality, 77*(4), 1085–1101. https://doi.org/10.1111/j.1467-6494.2009.00575.x

Holland, J. L. (1997). *Making vocational choices: A theory of vocational personalities and work environments* (3rd ed.). Psychological Assessment Resources.

Jäncke, L. (2009). Music drives brain plasticity. *F1000 Biology Reports, 1*(10): 78. https://doi.org/10.3410/B1-78

John, O. P., & Srivastava, S. (1999). The Big Five trait taxonomy: History, measurement, and theoretical perspectives. In L. A. Pervin & O. P. John (Eds.), *Handbook of personality: Theory and research* (pp. 102–138). Guilford Press.

Kragness, H. E., Swaminathan, S., Cirelli, L. K., & Schellenberg, E. G. (2021). Individual differences in musical ability are stable over time in childhood. *Developmental Science*. Advance online publication. https://doi.org/10.1111/desc.13081

Kuckelkorn, K. L., de Manzano, O., & Ullén, F. (2021). Musical expertise and personality—differences related to occupational choice and instrument category. *Personality and Individual Differences, 173*: 110573. https://doi.org/10.1016/j.paid.2020.110573

Lima, C. F., Correia, A. I., Müllensiefen, D., & Castro, S. L. (2020). Goldsmiths Musical Sophistication Index (Gold-MSI): Portuguese version and associations with socio-demographic factors, personality and music preferences. *Psychology of Music, 48*(3), 376–388. https://doi.org/10.1177/0305735618801997

McCrae, R. R, & John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of Personality, 60*(2), 175–215. https://doi.org/10.1111/j.1467-6494.1992.tb00970.x

Miles, C. C. (1926). *The early mental traits of three hundred geniuses*. Stanford University Press.

Mosing, M. A., Madison, G., Pedersen, N. L., Kuja-Halkola, R., & Ullén, F. (2014). Practice does not make perfect: No causal effect of music practice on music ability. *Psychological Science, 25*(9), 1795–1803. https://doi.org/10.1177/0956797614541990

Mosing, M. A., Madison, G., Pedersen, N. L., & Ullén, F. (2016). Investigating cognitive transfer within the framework of music practice: Genetic pleiotropy rather than causality. *Developmental Science, 19*(3), 504–512. https://doi.org/10.1111/desc.12306

Mosing, M. A., & Ullén, F. (2018). Genetic influences on musical specialization: A twin study on choice of instrument and music genre. *Annals of the New York Academy of Sciences, 1423*, 427–434. https://doi.org/10.1111/nyas.13626

Mrazek, M. D., Phillips, D. T., Franklin, M. S., Broadway, J. M., & Schooler, J. W. (2013). Young and restless: Validation of the Mind-Wandering Questionnaire (MWQ) reveals disruptive impact of mind-wandering for youth. *Frontiers in Psychology, 4*: 560. https://doi.org/10.3389/fpsyg.2013.00560

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE, 9*(2): e89642. https://doi.org/10.1371/journal.pone.0089642

Nussenbaum, K., Scheuplein, M., Phaneuf, C. V., Evans, M. D., Hartley, C. A. (2020). Moving developmental research online: Comparing in-lab and web-based studies of model-based reinforcement learning. *Collabra: Psychology, 6*(1): 17213. https://doi.org/10.1525/collabra.17213

Patel, A. D. (2011). Why would musical training benefit the neural encoding of speech? The OPERA hypothesis. *Frontiers in Psychology, 2*:142. https://doi.org/10.3389/fpsyg.2011.00142

Raven, J. C. (1965). *Advance Progressive Matrices, Sets I and II*. Psychological Corporation.

Sala, G., & Gobet, F. (2020). Cognitive and academic benefits of music training with children: A multilevel meta-analysis. *Memory & Cognition, 48*(8), 1429–1441. https://doi.org/10.3758/s13421-020-01060-2

Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging, 30*(4), 507-514. https://doi.org/10.1016/j.neurobiolaging.2008.09.023

Sauce, B., & Matzel, L. D. (2018). The paradox of intelligence: Heritability and malleability coexist in hidden gene-environment interplay. *Psychological Bulletin, 144*(1), 26–47. https://doi.org/10.1037/bul0000131

Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology, 102*(3), 283–302. https://doi.org/10.1111/j.2044-8295.2010.02000.x

Schellenberg, E. G. (2020). Correlation = causation? Music training, psychology, and neuroscience. *Psychology of Aesthetics, Creativity, and the Arts, 14*(4), 475–480. https://doi.org/10.1037/aca0000263

Schellenberg, E. G., & Mankarious, M. (2012). Music training and emotion comprehension in childhood. *Emotion, 12*(5), 887–891. https://doi.org/10.1037/a0027971

Simonton, D. K. (2006). Presidential IQ, openness, intellectual brilliance, and leadership: Estimates and correlations for 42 US chief executives. *Political Psychology, 27*(4), 511–639. https://doi.org/10.1111/j.1467-9221.2006.00524.x

Simonton, D. K. (2009). Creative genius in classical music. *The Psychologist, 22*(12), 1076–1078.

Steele, C. J., & Zatorre, R. J. (2018). Practice makes plasticity. *Nature Neuroscience, 21*(12), 1645–1646. https://doi.org/10.1038/s41593-018-0280-4

Sternberg, R. J. (1985). *Beyond IQ: A triarchic theory of intelligence*. Cambridge University Press.

Swaminathan, S., & Kragness, H. E., & Schellenberg, E. G. (2021). The Musical Ear Test: Norms and correlates from a large sample of Canadian undergraduates. *Behavior Research Methods.* Advance online publication. https://doi.org/10.3758/s13428-020-01528-8

Swaminathan, S., & Schellenberg, E. G. (2019). Music training and cognitive abilities: Associations, causes, and consequences. In M. H. Thaut & D. A. Hodges (Eds.), *The Oxford handbook of music and the brain* (pp. 645–670). Oxford University Press. http://dx.doi.org/10.1093/oxfordhb/9780198804123.013.26

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude? *Intelligence, 62*, 119–124. http://dx.doi.org/10.1016/j.intell.2017.03.005

Sylvia, P. J., Nusbaum, E. C., Berg, C., Martin, C., & O'Connor, A. (2009). Openness to experience, plasticity, and creativity: Exploring lower-order, high-order, and interactive effects. *Journal of Research in Personality, 43*(6), 1087–1090. https://doi.org/10.1016/j.jrp.2009.04.015

Tierney, A., & Kraus, N. (2013). Music training for the development of reading skills. *Progress in Brain Research, 207*, 209–241. https://doi.org/10.1016/B978-0-444-63327-9.00008-4

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010). The Musical Ear Test, a new reliable test for measuring musical competence. *Learning and Individual Differences, 20*(3), 188–196. https://doi.org/10.1016/j.lindif.2010.02.004

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence–Second Edition (WASI-II)* [Database record]. APA PsycTests. https://doi.org/10.1037/t15171-000

Zhang, J. D., Susino, M., McPherson, G. E., & Schubert, E. (2020). The definition of a musician in music psychology: A literature review and the six-year rule. *Psychology of Music, 48*(3), 389–409. https://doi.org/10.1177/0305735618804038

CHAPTER 5

Individual Differences in Musical Ability among Adults with no Music Training

Correia, A. I., Vincenzi, M., Vanzella, P., Pinheiro, A. P., Schellenberg, E. G., & Lima, C. F. (2023). Individual differences in musical ability among adults with no music training. *Quarterly Journal of Experimental Psychology*, *76*(7), 1585–1598. https://doi.org/10.1177/17470218221128557

Abstract

Good musical abilities are typically considered to be a consequence of music training, such that they are studied in samples of formally trained individuals. Here, we asked what predicts musical abilities in the absence of music training. Participants with no formal music training (N = 190) completed the Goldsmiths Musical Sophistication Index, measures of personality and cognitive ability, and the Musical Ear Test (MET). The MET is an objective test of musical abilities that provides a Total score and separate scores for its two subtests (Melody and Rhythm), which require listeners to determine whether standard and comparison auditory sequences are identical. MET scores had no associations with personality traits. They correlated positively, however, with informal musical experience and cognitive abilities. Informal musical experience was a better predictor of Melody than of Rhythm scores. Some participants (12%) had Total scores higher than the mean from a sample of musically trained individuals (≥ 6 years of formal training), tested previously by Correia et al. (2022). Untrained participants with particularly good musical abilities (top 25%, n = 51) scored higher than trained participants on the Rhythm subtest and similarly on the Melody subtest. High-ability untrained participants were also similar to trained ones in cognitive ability, but lower in the personality trait openness-to-experience. These results imply that formal music training is not required to achieve musician-like performance on tests of musical and cognitive abilities. They also suggest that informal music practice and music-related predispositions should be considered in studies of musical expertise.

Keywords: music, ability, training, cognition, personality

5.1. Introduction

Musical abilities and behaviors vary widely across individuals. Some people do not value music and struggle with music-related activities (e.g., singing in tune, dancing in time), whereas others have sophisticated musical skills and display a diverse repertoire of musical behaviors. In the scientific literature and in Western societies, good musical abilities tend to be equated with formal training and being proficient at singing or playing a musical instrument (e.g., Ullén et al., 2014; Wallentin et al., 2010).

Accordingly, most of the relevant literature has compared groups of formally trained individuals to those with no training, so-called *nonmusicians*, whether the design is cross-sectional (e.g., Lima & Castro, 2011; MacDonald & Wilbiks, 2021; Schellenberg & Mankarious, 2012; Tierney et al., 2020) or longitudinal (e.g., Martins et al., 2018; Roden et al., 2014; Schellenberg et al., 2015; Thompson et al., 2004). Findings from these studies inform debates about associations between music lessons and nonmusical abilities (e.g., speech perception, executive functions). Although transfer effects of music training remain the focus of much debate (e.g., Bigand & Tillmann, 2022; Kragness et al., 2021; Martins et al., 2021; Sala & Gobet, 2020; Schellenberg, 2020; Degé, 2021), learning to play an instrument involves honing several cognitive skills, such as attention, memory, and self-discipline (Wan & Schlaug, 2010). Music lessons might therefore have relevant implications for education, health, and well-being.

Because researchers are typically interested in possible side-effects of formal music training (i.e., plasticity or transfer), even when causation cannot be inferred (see Schellenberg, 2020), untrained individuals tend to be treated as a homogeneous group regarding their musicality, or musical ability. The presumption is that untrained individuals have poor musical abilities, such that music training and musical abilities are conflated. The fact that many studies of associations between music training and nonmusical abilities do *not* measure musical abilities confirms that musicality is thought to be high in the trained group and low in the untrained one.

Recent findings raise doubts about this assumption. First, an established genetic component to musical ability and achievements means that natural variation in musical abilities is expected even in the absence of training (Gingras et al., 2015; Mosing et al., 2014; Tan et al., 2014). Second, when music training is held constant, individuals with good musical ability show enhanced nonmusical skills including speech processing (Mankel & Bidelman 2018; Swaminathan & Schellenberg, 2017) and vocal emotion recognition (Correia et al., 2020), mirroring the enhancements seen in formally trained musicians. Indeed, when music training and musical ability are considered jointly, associations between training and nonmusical abilities often disappear (Correia et al. 2020; Swaminathan et al., 2017, 2018; Swaminathan & Schellenberg, 2020). Third, some musical capacities are achieved simply by engaging in music-related activities, such as listening to music (e.g., Bigand & Poulin-Charronnat, 2006; Larrouy-Maestri et al., 2017), or through untutored learning experiences (e.g., Green, 2002; Veblen, 2012).

Classifying someone as musically trained or untrained is not straightforward (Zhang et al., 2020). Here, we considered untrained individuals to be those with *no* formal music lessons—either instrumental or voice. Our focus on formal lessons is consistent with Zhang et al.'s (2020) review of the literature, which concluded that six years of music lessons or training represent a consensus for classifying someone as a musician, and/or recruitment from music schools. Others have considered a cut-off of two years of lessons to classify participants as musically experienced or inexperienced (e.g., Dowling et al., 1995). For conceptual and theoretical clarity, we opted for a more conservative definition to rule out any potential contribution of formal lessons. This decision left us with the problem of individuals who are clearly musicians even though they have no formal training (e.g., Louis Armstrong, David Bowie). Formal training and untutored learning are two poles of a continuum (Folkestad, 2006; Green, 2002; Veblen, 2012), which typically differ in learning style (formal vs. informal), context (inside institutional settings vs. outside), and goals. Nevertheless, in research on music training, participants without formal music lessons but who practice informally are often included in the same group as participants who never played a musical instrument (e.g., Swaminathan et al., 2017, 2018). Informal practice is typically not even measured. To the best of our knowledge, ours is the first study to examine untutored learning and informal practice in detail.

Because untrained listeners can vary widely in musical ability, due to both genetic factors and informal musical experiences, integrating these differences into studies of musical expertise is bound to be informative. Such integration would be consistent with perspectives on musicality as a broad and multifaceted concept (Müllensiefen et al., 2014). Expanding our understanding of musical abilities beyond the narrow scope of formal music lessons also has implications for the interpretation of findings from studies on music training. For example, if variables typically correlated with training also correlate with musical ability in the absence of training, training would be sufficient but not necessary to explain the advantages observed in musicians. Rather, predispositions and/or informal experiences could influence the development of musical and/or non-musical abilities, *and* the likelihood of taking music lessons. Moreover, if musical abilities and related variables can be as high in subgroups of untrained individuals as in trained musicians, the specificity of training-related differences would be called into question. In short, understanding musicality in the absence of music lessons is essential for a nuanced conceptualization of musical abilities, and to tease apart training-specific from more general associations.

In the present investigation, we focused on a sample that included only individuals with no formal training in music. Some studies examining correlates of musical ability held music training constant by statistical means (e.g., Kragness et al., 2021, Swaminathan et al., 2017, 2018, 2021), whereas our study held music training constant by selective sampling. Although a previous study examined musically untrained *children* (James et al., 2020), ours is the first to use this approach with adults, who are more likely to have a history of informal music practice. We assessed musical ability objectively using the Musical Ear Test (MET, Wallentin et al., 2010), which has separate subtests for melody and rhythm processing. Participants also completed the Goldsmith's Musical Sophistication Index (Gold-MSI, Müllensiefen et al., 2014), a self-report questionnaire that asks about formal and informal musical behaviors, experience, and skills. We additionally measured participants' general cognitive abilities and personality traits, two domains often considered in music-training studies (e.g., Kuckelkorn et al., 2021; Swaminathan & Schellenberg, 2018). Finally, we identified untrained listeners from our sample who performed well on the MET, so that we could compare them with trained listeners tested previously but identically by Correia et al. (2022).

Our main goal was to identify correlates of musical abilities among individuals with no formal music lessons. We were particularly interested in whether cognitive abilities and personality traits that predict years of music lessons (e.g., Corrigall et al., 2013) also predict musical ability among untrained individuals. In samples of individuals who vary widely in music training, musical ability is associated positively with cognitive ability and with the personality trait openness-to-experience (hereafter, *openness;* e.g., Swaminathan et al., 2021; Swaminathan & Schellenberg, 2018). We also asked whether musical ability among untrained individuals would be associated positively with (1) self-reports of musical sophistication measured by the Gold-MSI subscales, and (2) informal music learning and practice measured by specific Gold-MSI items (e.g., number of instruments played, amount of practice). These questions were motivated by previous findings using different but objective measures of musical ability, and by the idea that musical ability relates to multiple forms of engagement with music in addition to lessons (Lee & Müllensiefen, 2020; Müllensiefen et al., 2014). Because formal music lessons predict melody skills better than rhythm skills (Correia et al., 2022; Swaminathan et al., 2021), we also asked whether untutored practice and playing might be differentially associated with the two MET subtests.

A secondary objective was to identify untrained listeners with good musical abilities—so-called *musical sleepers* (Law & Zentner, 2012)—and to compare them to trained individuals tested previously by Correia et al. (2022) in terms of their musical, cognitive, and personality characteristics. We expected that trained individuals, with their years of formal musical experiences, would score higher on the Gold-MSI. Performance on the MET was bound to tell a more interesting story, regardless of the results. If the musical abilities of the best performing untrained listeners fall below those of trained listeners, music training would appear to provide a *unique* pathway for high levels of musicality. Alternatively, if a substantial proportion of untrained participants display levels of musical ability comparable to their trained counterparts, factors other than training (i.e., genetics, informal musical experiences) would be implicated. For measures of cognitive ability and personality, the available literature precluded clear predictions about differences between high-ability untrained participants and trained ones, because ours is the first study to examine these differences, and the first to isolate effects of formal training.

5.2. Method

5.2.1. Participants

Ethical approval for the study protocol was obtained from the local ethics committee at Iscte-University Institute of Lisbon (reference 07/2021). Informed consent was collected from each participant at the beginning of the experiment. A sample of 861 participants was recruited initially, mainly in response to advertisements posted on social media (e.g., Facebook, LinkedIn), but also via email and snowball sampling. Subsets of this sample were used previously to document the psychometric properties of the online testing format (Correia et al., 2022, $N = 608$), and to examine how professional musicians differ from other individuals (Vincenzi et al., 2022, $N = 642$).

Because our interest here was in musically untrained individuals, the present sample comprised the 190 individuals (132 women, 58 men) with *no* formal music lessons (instrumental or voice). This criterion was stricter than the one typically used in the literature, in which individuals with up to 2-3 years of lessons are also included in the untrained/nonmusician category (e.g., Anaya et al., 2017; Bidelman et al., 2013; Mankel & Bidelman, 2018). Although our participants had no formal training, 43 answered *yes* when asked if they can play an instrument (or sing), and 27 of these were currently playing (detailed information about musical behaviors other than lessons is provided in Supplementary Table 5.1).

Additional untrained participants were tested but excluded because of self-reported hearing disabilities ($n = 2$), unspecified gender ($n = 1$), having a music-related job ($n = 1$), or performing significantly *below* chance levels (i.e., scores < 19, chance = 26, normal approximation to the binomial, two-tailed) on either the Melody or Rhythm subtest of the MET ($n = 32$). Such low levels of performance were uninterpretable in terms of musical ability and indicated failing to attend to the task.

Participants ranged in age from 18 to 73 years (median = 27). The average was 32.0 years ($SD = 16.0$). In terms of education, most had a university degree (bachelor's: $n = 36$, master's: $n = 55$, Ph.D.: $n = 14$). The rest had completed high school ($n = 85$). Preliminary analyses revealed that performance on MET Melody, Rhythm, and Total Scores improved with increased age, *r*s > .26, *p*s < .001, and education, *r*s > .28, *p*s < .001. Accordingly, age (in years) and education (coded 1-4) were held constant in the analyses that follow. Because men and women scored similarly on the MET, *p*s > .1, gender was not considered further.

To recruit a large and diverse sample, the study was available in four languages (English, Italian, Brazilian Portuguese, and European Portuguese). Our goal was to test as many participants as possible. Post-hoc power analyses conducted with G*Power 3.1 (Faul et al., 2007) confirmed that our sample of 190 musically untrained individuals provided power of 80% to detect partial correlations of .20, with two covariates (age, education) held constant. For group comparisons (two covariates), a sub-sample of 51 high-ability untrained participants was compared to 220 trained participants (from Correia et al., 2022). These samples provided more than 80% power to detect small effect sizes (i.e., partial $\eta^2 \geq 0.03$). The full dataset is available on the OSF platform (https://osf.io/564xy/?view_only=b545f24df7af4a21908c2583032255a7).

5.2.2. Measures

Gorilla Experiment Builder (Anwyl-Irvine et al., 2020), an online platform for psychological research, was used to adapt questionnaires and tasks, program the experiment, and collect the data. Original measures were used for the English version of the program. Published translations for the other languages (Italian, Brazilian Portuguese, European Portuguese) were used when available. When a measure was not validated for a target language, a translated version was created by bilinguals, who were native speakers of the target language and fluent in English. Online versions of all tests had good reliability and validity (Correia et al., 2022), and all are available on Gorilla (https://app.gorilla.sc/openmaterials/218554).

5.2.2.1. Musical Expertise

Musical Ear Test (MET). The MET was our objective measure of musical ability (Wallentin et al., 2010). The MET has good reliability and validity, both for in-person (Swaminathan et al., 2021) and online (Correia et al., 2022) testing. It has two subtests: Melody and Rhythm. On each trial, participants hear a pair of short sequences of piano tones in the Melody subtest, and drumbeats in the Rhythm subtest, and judge whether the two sequences are identical. When the sequences differ, at least one tone (Melody) or one inter-onset interval (Rhythm) is altered. Both subtests include 52 trials (half *identical*) and they are always presented in the same order—Melody then Rhythm—with two initial practice trials for both subtests. Feedback is provided on the practice trials but not on the test trials. Participants have a limited time (1500 ms for Melody, 1659 to 3230 ms for Rhythm) to answer before the presentation of the next trial. Because time intervals between trials are fixed, the MET has the same duration for each participant (20 min; for more details regarding the MET, see Swaminathan et al., 2021).

Before testing began, participants were asked to use headphones and to avoid distractions throughout the test. The number of correct responses was calculated separately for each participant for both subtests and for Total scores. Following the test's developers (Wallentin et al., 2010), missing responses were considered incorrect.

Goldsmiths Musical Sophistication Index (Gold-MSI). The Gold-MSI is a self-report questionnaire that includes 38 items asking about behaviors, experiences, and skills related to music (Müllensiefen et al., 2014; Lima et al., 2020). For scoring purposes, items are combined to form 5 subscales: Active Engagement (9 items; e.g., *I listen attentively to music for __ per day*), Perceptual Abilities (9 items; e.g., *I can tell when people sing or play out of tune*), Music Training (7 items; e.g., *I have had formal training in music theory for __ years*), Singing Abilities (7 items; e.g., *I am able to hit the right notes when I sing along with a recording*), and Emotions (6 items; e.g., *I often pick certain music to motivate or excite me*). A General Factor score (18 items) is also calculated based on representative items from each subscale. Participants respond on 7-point scales. For most items, they rate their agreement (1 = *completely disagree* to 7 = *completely agree*). For the final seven items, response options vary from item to item. In the example provided above for the Active Engagement subscale, seven response alternatives increase monotonically from *0-15 min* to *4 hours or more*.

One specific item on the Music Training subscale [*I have had _ years of formal training on a musical instrument (including voice) during my lifetime*] was used to classify participants as musically untrained. Anyone who selected option 1 (i.e., 0 years) was considered untrained. Thus, Music Training subscale scores were not included in the analyses, but the other items from the subscale (except for one about formal training in music theory) remained potentially relevant because they measured experiences that do not require a formal learning context, such as amount of practice and number of musical instruments played.

5.2.2.2. Cognitive Abilities

General Cognitive Ability. The Matrix Reasoning Item Bank (MaRs-IB; Chierchia et al., 2019) is an online test of abstract (nonverbal) reasoning similar to Raven's Advanced Progressive Matrices (Raven, 1965). It has been used successfully in previous studies as a measure of general cognitive ability (hereafter, *cognitive ability*; e.g., Correia et al., 2022; Nussenbaum et al., 2020). The test includes 80 trials, each comprising a matrix with nine cells in a 3 x 3 configuration, with each cell containing abstract shapes that vary on one to four dimensions (colour, size, shape, and location). The cell in the bottom-right corner is always empty, and participants choose, from four alternatives, the one that logically completes the matrix.

The MaRs-IB has a duration of 8 min, regardless of the number of responses given by each person. Participants are told in advance that they have a maximum of 30 s to respond to each trial, but they are not informed about the task duration, which means that the number of trials participants complete can vary from 16 to 80. If a participant responds to all the trials in less than 8 min, matrices are re-presented in the same order, but responses from repeated trials are not considered in the final score. Following the scale's developers (Chierchia et al., 2019), cognitive ability was measured as the proportion of correct responses (i.e., correct responses/number of responses), calculated for each participant after excluding responses given in less than 250 ms. For statistical analyses, proportions were logit-transformed.

Mind-Wandering Questionnaire (MWQ). The MWQ (Mrazek et al., 2013) was included for exploratory purposes, to measure participants' ability to sustain attention and focus. Because this cognitive ability, like other domain-general ones, is important for many musical activities, we speculated that it would be associated positively with musical ability and experience. The questionnaire includes 5 sentences that represent distinct trait levels of mind-wandering (e.g., *I mind-wander during lectures or presentations*). Participants are asked to evaluate how often each one applies to them, using a 6-point rating scale (1 = *almost never* to 6 = *almost always*).

An average score indicates the frequency of mind-wandering, such that *lower* scores are indicative of higher levels of sustained attention and focus.

5.2.2.3. Personality

Big-Five Inventory (BFI). The BFI (John et al., 1991, 2008) is a self-report questionnaire used frequently to measure personality traits from the five-factor model (McCrae & John, 1992): Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness-to-Experience. The BFI comprises 44 items, with each item representative of one of the traits (e.g., Extraversion: *I see myself as someone who is talkative*; Agreeableness: *I see myself as someone who likes to cooperate with others*). Using a 5-point rating scale, participants evaluate how much they agree with each expression (1 = *disagree strongly* to 5 = *agree strongly*). A mean score is calculated for each personality trait.

5.2.3. Procedure

To access the study, participants went online and clicked a hyperlink that led them directly to the *Gorilla* platform (http://www.gorilla.sc/). After they confirmed their willingness to participate and responded to demographic questions (e.g., age, gender, education), they completed one 40-min online session. The questionnaires and tasks were always presented in the same order: the MWQ, Gold-MSI, BFI, MaRs-IB, and finally the MET. The fixed order meant that the objective skills-based tests (MaRs-IB, MET), which were longer in duration, were always at the end of the testing session. After completing all tasks, participants received feedback about their musical abilities and personality. Providing feedback at the end (mentioned during recruitment) was intended to improve motivation to participate and to complete the entire test session.

5.3. Results

5.3.1. Analysis

In the analyses that follow, we report standard frequentist statistics. Instead of correcting for multiple tests, we also report results from Bayesian analyses using JASP 0.16.1 (JASP Team, 2022) and default priors. Bayesian statistics allowed us to determine whether the observed data were more likely under the null or alternative hypothesis, and whether the evidence was negligible ($BF_{10} < 3$), substantial ($3 < BF_{10} < 10$), strong ($10 < BF_{10} < 30$), very strong ($30 < BF_{10} < 100$), or decisive ($BF_{10} > 100$) in this regard (Jeffreys, 1961; Jarosz & Wiley, 2014).

Weak but significant results from frequentist statistics were considered unreliable if they were not accompanied by substantial (or stronger) evidence. Bayesian analyses also allowed for a clearer interpretation of null findings when the observed data were substantially more likely (i.e., $BF_{10} < .333$) under the null than the alternative hypothesis.

The first set of analyses examines individual differences that predict musical ability among participants with no music lessons (age and education held constant). We then identified untrained listeners with good musical abilities (those scoring in the top 25% of the MET Total score range) and asked how they compare to formally trained ones in their musical, cognitive and personality characteristics. The trained participants were tested previously but identically by Correia et al. (2022).

5.3.2. Musically Untrained Participants

Preliminary analyses confirmed that MET Melody, Rhythm, and Total scores did not vary as a function of the language of the test, *F*s < 1. Test language was not considered further. Descriptive statistics for the MET, Gold-MSI subscales, personality traits from the BFI, and cognitive abilities (MaRs-IB, MWQ) are provided in Supplementary Table 5.1. The distribution of MET Total scores was unimodal and approximately normal (Shapiro-Wilk test, $p = .542$). The observed data provided very strong evidence that mean levels of performance were lower than those from published norms (72.5; Swaminathan et al., 2020), $t(189) = 3.54$, Cohen's $d = .257$, $BF_{10} = 32.0$. This result was expected because the normative sample included individuals who were musically trained.

MET Melody and Rhythm scores were correlated positively, $r = .579$, $N = 190$, $p < .001$, $BF_{10} > 100$, and the association was similar in magnitude to that reported by Swaminathan et al. (2020; $r = .489$), $z = 1.71$, $p = .087$. Comparisons of correlations from dependent samples were conducted with Psychometrica (https://www.psychometrica.de/correlation.html).

Table 5.1 reports partial correlations between the MET and the other variables (age and education held constant). Even for our sample of untrained participants, musical ability, as measured by the MET Melody, Rhythm, and Total scores, correlated positively with Gold-MSI scores. The one exception was for the subscale Active Engagement, for which the observed data provided substantial evidence for the *null* hypothesis for Rhythm and Total scores. The association between Melody scores and Active Engagement was negligible, as was the association between Rhythm and Singing Abilities. In all other instances, evidence for a positive association ranged from substantial to decisive. In other words, as performance on our objective measures of musical ability increased, so did self-reports of singing ability, emotional responding to music, perceptual skills, and overall musical sophistication.

Table 5.1. Pairwise Correlations Between MET Scores and Gold-MSI Subscales, Personality Dimensions, Cognitive Abilities, and Mind-Wandering (Age and Education Held Constant, *N* = 190).

	MET Total			MET Melody			MET Rhythm		
	r	*p*	BF_{10}	*r*	*p*	BF_{10}	*r*	*p*	BF_{10}
MET									
Melody	.894	<.001	>100	-	-	-	-	-	-
Rhythm	.883	<.001	>100	.579	<.001	>100	-	-	-
Gold-MSI									
Active Engagement	.045	.535	.261	.068	.351	.340	.011	.880	.237
Perceptual Abilities	.294	<.001	>100	.295	<.001	>100	.227	.002	22.6
Singing Abilities	.230	.002	24.6	.245	<.001	49.1	.161	.027	2.27
Emotion	.270	<.001	>100	.279	<.001	>100	.199	.006	7.54
General Factor	.287	<.001	>100	.305	<.001	>100	.203	.005	8.88
Personality									
Extraversion	-.024	.746	.229	-.051	.484	.285	.011	.885	.236
Agreeableness	.154	.035	1.76	.130	.075	.990	.144	.048	1.43
Conscientiousness	-.029	.691	.235	-.035	.635	.252	-.017	.821	.240
Neuroticism	.036	.621	.245	.022	.769	.236	.043	.554	.275
Openness	.115	.115	.798	.124	.090	.863	.080	.275	.407
Cognition									
Cognitive Ability	.333	<.001	>100	.276	<.001	>100	.316	<.001	>100
Mind Wandering	.076	.303	.359	.068	.356	.337	.067	.364	.343

For personality traits (Table 5.1), there were no significant correlations between MET scores and Extroversion, Conscientiousness, or Neuroticism, and the data provided substantial evidence for the null hypothesis in each instance. Although Agreeableness was positively correlated with Rhythm and Total scores, the evidence was negligible, as it was for Melody, and for all associations between Openness and MET scores. Finally, performance on the MET had strong positive associations with cognitive ability, with evidence deemed decisive by Bayesian analyses. There were no significant associations with mind wandering, however, although evidence favouring the null hypothesis was negligible. In any event, the results confirmed that among individuals with no music training, musical ability was correlated positively with cognitive ability and with other musical behaviors and experiences.

Table 5.2 provides partial correlations between the MET and six of the seven individual items from the Gold-MSI Music Training subscale, excluding the item that measured years of formal training on a musical instrument (or voice), which did not vary in our sample. MET scores had no association with formal training in music theory or the degree to which participants identified as musicians, and the observed data provided substantial evidence for the null hypotheses. MET scores correlated positively with the other four items, however, which measured *untutored* music learning and practice. Higher scores on the MET were predicted by years of music practice, daily hours of practice, compliments received about musical ability, and number of instruments played. In all instances, the observed data provided substantial or stronger evidence. Because these four items from the Gold-MSI were intercorrelated, $r\text{s} \geq .388$, $N = 190$, $p\text{s} < .001$, we extracted a principal component (hereafter *Music Practice*) to use in subsequent analyses. This latent variable accounted for 67.4% of the variance in the original four items, and each item loaded highly (> .7) onto the latent variable. As shown in Table 5.2, Music Practice maximized associations with MET scores, although the correlation was significantly higher for the Melody than for the Rhythm subtest, $z = 2.60$, $p = .009$.

Table 5.2. Pairwise Correlations Between MET Scores and Individual Items from the Music Training Subscale of the Gold-MSI (Age and Education Held Constant, N = 190).

	MET Total			MET Melody			MET Rhythm		
	r	*p*	BF_{10}	*r*	*p*	BF_{10}	*r*	*p*	BF_{10}
Gold-MSI Item									
Duration of Practice	.333	<.001	>100	.355	<.001	>100	.234	.001	30.2
Compliments	.243	<.001	43.7	.257	<.001	86.1	.173	.018	3.17
Identity	.060	.410	.300	.053	.469	.289	.054	.460	.302
Hours of Practice	.331	<.001	>100	.373	<.001	>100	.212	.004	12.3
Music Theory	.052	.478	.276	.060	.411	.310	.032	.667	.255
Instruments Played	.343	<.001	>100	.379	<.001	>100	.227	.002	22.6
Music Practice*	.383	<.001	>100	.419	<.001	>100	.258	<.001	92.6

*Principal component extracted from the other items (except Music Theory and Identity).

Because our measure of Music Practice was novel, we asked whether it was associated with individual differences in openness and cognitive ability, as music training is. The observed data provided very strong evidence that Music Practice was associated positively with openness, $r = .238$, $p < .001$, $BF_{10} = 38.5$, but there was no association with cognitive ability, $r = .118$, $p = .105$, $BF_{10} = .937$, although evidence for the null hypothesis was negligible. In short, individuals who were high in openness had an increased likelihood of informal music practice.

In the following analyses, we used multiple regression to determine which combination of variables best predicted MET scores. The model included age, education, the Gold-MSI

General Factor (to reduce collinearity), Music Practice, and cognitive ability. Results are provided in Table 5.3. The model was significant in each case, with age and cognitive ability making significant independent contributions in each instance, and Music Practice making a significant independent contribution for Melody and Total scores, but not for Rhythm scores. For all significant partial associations, Bayesian analyses confirmed that the observed data provided strong to decisive evidence. For the association between Music Practice and Rhythm scores, Bayesian analyses indicated that the observed data were equally likely under the null and alternative hypotheses. As before, the partial association between Music Practice and Melody scores (r = .272) was stronger than the partial association between Music Practice and Rhythm Scores (r = .125), z = 2.09, p = .037.

Table 5.3. Multiple Regression Results Predicting MET Scores from Age, Education, the Gold-MSI General Factor, Music Practice, and Cognitive Ability

	MET Total			MET Melody			MET Rhythm		
	R^2	p	BF_{10}	R^2	p	BF_{10}	R^2	p	BF_{10}
Model	.337	<.001	>100	.319	<.001	>100	.239	<.001	>100
	ß	p	BF_{10}	ß	p	BF_{10}	ß	p	BF_{10}
Predictors									
Age	.314	<.001	>100	.286	<.001	>100	.280	<.001	78.2
Education	.142	.054	1.17	.146	<.052	1.25	.110	.165	.585
Gold-MSI	.098	.228	.396	.081	.328	.321	.097	.268	.419
Music Practice	.261	.002	23.4	.316	<.001	>100	.149	.090	.915
Cognitive Ability	.299	<.001	>100	.238	<.001	84.5	.303	<.001	>100

5.3.3. Comparison of Musically Untrained and Trained Individuals

The next set of analyses compared our untrained participants with the 220 musically trained ones from Correia et al. (2022), each of whom had at least six years of lessons, as per the criterion used in most music-training research (Zhang et al., 2020). No trained individual had a Melody or Rhythm score that was significantly below chance levels. Figure 1 illustrates descriptive statistics for MET Total scores separately for the two groups. An Analysis of Covariance with music training as a between-subjects variable and two covariates (age, education) confirmed that Total scores for trained individuals were decisively higher than those for untrained individuals, $F(1, 403) = 134.69$, $p < .001$, partial $\eta^2 = .250$, $BF_{10} > 100$. Nevertheless, the distributions overlapped considerably. In fact, 12% of the untrained individuals (n = 23) scored above the mean (82.2) and median (82.5) for the trained individuals. The figure also shows considerable variation in MET Total scores for both groups, although scores varied more for the untrained compared to the trained participants. $F(1, 405) = 14.04$, $p < .001$ (Levene's test for equality of variances).

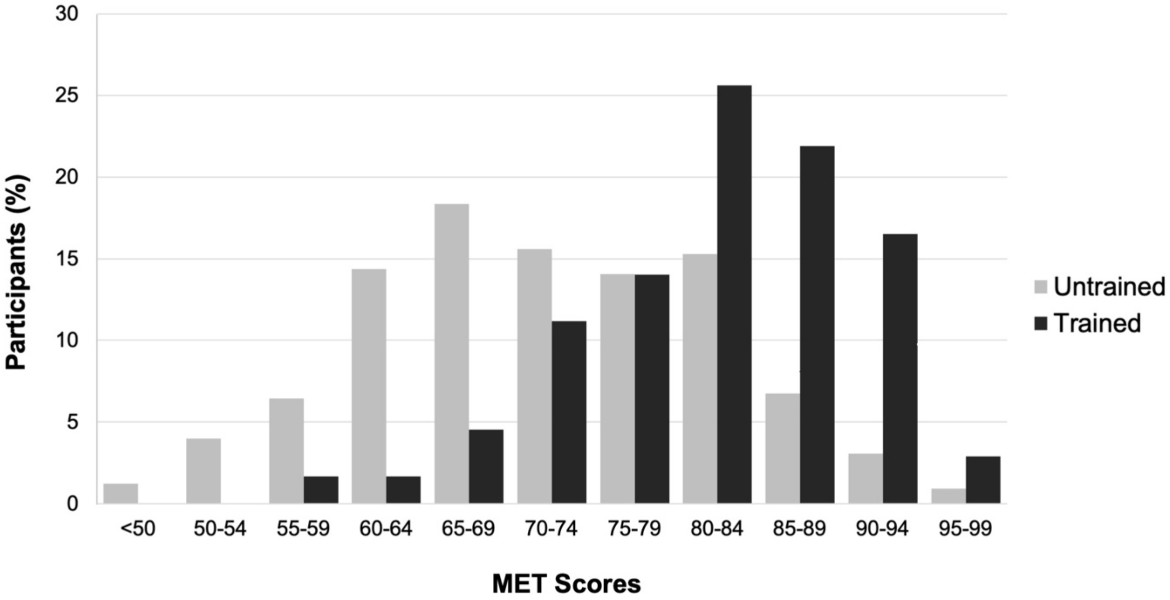

Figure 5.1. Distribution of MET total scores for untrained and trained participants

The overlap between distributions motivated us to ask if musically untrained individuals with high levels of ability are similar to trained individuals in terms of musical abilities, cognitive abilities, and personality. To avoid focusing on particularly unusual or extreme cases, we selected untrained individuals who had MET Total scores in the top 25% (i.e., MET Total score ≥ 78 out of 104; $n = 51$).

Compared to the trained individuals from Correia et al. (2022), the high-ability untrained participants did not differ in age, education, or gender, *p*s > .09. There was decisive evidence, however, that the trained individuals were more likely to play a musical instrument (or sing), $\chi^2(1, N = 271) = 112.04$, $p < .001$, $\varphi = .643$, $BF_{10} > 100$ (trained: 218/220, untrained: 25/51), and to be currently playing music, $\chi^2(1, N = 271) = 52.23$, $p < .001$, $\varphi = .439$, $BF_{10} > 100$ (trained: 177/220, untrained: 15/51).

As shown in Table 5.4, high-ability untrained participants had MET Total scores similar to those of the trained participants, although evidence for the null hypothesis was negligible. The groups also did not differ on the Melody subtest, with substantial evidence favouring the null hypothesis. There was strong evidence, however, that *untrained* participants had *higher* Rhythm scores, which, in turn, led to strong evidence for an interaction between group and subtest, $F(1, 264) = 11.45$, $p < .001$, partial $\eta^2 = .042$, $BF_{10} = 17.7$.

Table 5.4. Descriptive Statistics for High-Ability Musically Untrained Participants (Top 25%) and Trained Participants from Correia et al. (2022). Age and Education Were Held Constant in Statistical Comparisons.

	High-Ability Untrained (n = 51)	Trained (n = 220)				
	M (SD)	M (SD)	F	p	BF_{10}	Partial η^2
MET						
Total	83.9 (5.2)	82.0 (8.3)	1.88	.171	.407	.007
Melody	41.5 (3.9)	41.9 (3.9)	< 1	.484	.206	.002
Rhythm	42.5 (3.2)	40.2 (4.5)	10.99	.001	27.5	.040
Gold-MSI						
Active Engagement	3.9 (1.3)	5.0 (0.9)	48.51	<.001	>100	.155
Perceptual Abilities	5.1 (1.1)	6.2 (0.6)	82.11	<.001	>100	.237
Singing Abilities	4.0 (1.6)	5.2 (0.9)	53.26	<.001	>100	.168
Emotion	5.6 (1.0)	6.0 (0.7)	8.13	.005	7.39	.030
General Factor	3.7 (1.2)	5.5 (0.7)	193.70	<.001	>100	.423
Music Practice	-1.6 (1.1)	0.4 (0.5)	334.70	<.001	>100	.559
Personality						
Extraversion	3.3 (0.9)	3.3 (0.8)	< 1	.888	.169	<.001
Agreeableness	3.9 (0.4)	3.9 (0.5)	< 1	.715	.179	<.001
Conscientiousness	3.7 (0.7)	3.7 (0.7)	< 1	.399	.232	.003
Neuroticism	3.0 (0.8)	3.0 (0.9)	< 1	.629	.183	<.001
Openness	3.9 (0.6)	4.2 (0.5)	21.76	<.001	>100	.076
Cognition						
Cognitive Ability	0.7 (0.8)	0.6 (0.7)	1.00	.318	.270	.004
Mind Wandering	3.2 (1.1)	3.0 (0.9)	4.76	.030	1.48	.018

For self-reports of musical sophistication (i.e., the subscales and general factor of the Gold-MSI), trained participants scored consistently higher than their untrained but high-ability counterparts. In fact, the observed data provided decisive evidence for a group difference on all subscales except Emotions, for which the evidence remained substantial. When we re-extracted the principal component (i.e., Music Practice, 63.2% of variance explained) using the same four items from the Gold-MSI Music Training subscale (excluding years of music lessons, music theory, and musical identity), musically trained individuals had decisively higher scores on this latent variable.

For personality traits, the trained group had decisively higher scores on openness, but not on any other personality trait, for which the observed data provided consistent and substantial support for *null* associations. There was also substantial evidence that the groups did not differ in cognitive ability. Finally, although the trained group had significantly lower mind-wandering scores, the evidence was negligible in this regard.

These findings did not change when we compared trained individuals to untrained individuals who scored in the top 20% (n = 40) or 30% (n = 58) for MET Total scores. Results are summarized in Supplementary Tables 5.2 and 5.3. Specifically, the untrained group scored higher on Rhythm scores, there was an interaction between MET subtest and group, the trained group had higher openness scores, and the trained group had higher scores on all Gold-MSI subscales, the general factor, and the latent Music Practice variable.

Finally, to isolate further the role of formal music lessons, we compared our high-ability untrained participants to trained participants who had equally high MET Total scores ($\geq$ 78, n = 163). Results are provided in Supplementary Table 5.4. The two high-ability groups did not differ in age, education, or gender, ps > .2, but there was decisive evidence that the trained participants were more likely to play a musical instrument (or sing), $\chi^2(1, N = 214) = 89.38$, $p < .001$, $\varphi = .643$, $BF_{10} > 100$ (trained: 162/163, untrained: 25/51), and to be currently playing, $\chi^2(1, N = 214) = 51.20$, $p < .001$, $\varphi = .489$, $BF_{10} > 100$ (trained: 134/163, untrained: 15/51). The trained group had substantially higher MET total scores, which stemmed from a decisive advantage on the Melody subtest. The former advantage for untrained participants on the Rhythm subtest became non-significant, although evidence for a null association was negligible. Nevertheless, the interaction between group and subtest remained decisive, $F(1, 208) = 18.42$, $p < .001$, partial $\eta^2 = .081$, $BF_{10} > 100$. The results remained unchanged for the other individual-difference variables (Gold-MSI, personality, and cognitive abilities).

5.4. Discussion

Variables that predicted musical abilities among musically untrained individuals included higher levels of cognitive ability and self-reported musical experiences and skills, particularly untutored music practice and playing. Untrained participants varied widely in musical abilities, however, and there was substantial overlap in the distribution of trained and untrained participants (Figure 1). In fact, many untrained participants (12%) had better musical abilities than the average trained participant. Moreover, untrained participants with particularly good musical abilities (MET scores in the top 25%) were comparable to trained musicians in cognitive ability and melody processing, and better in rhythm processing. They were lower, however, in the personality trait openness.

Our results from the top untrained performers (regarding musical and cognitive ability) are consistent with evidence of genetic contributions to musical ability and achievement (Hambrick & Tucker-Drob, 2015; Mosing et al., 2014; Tan et al., 2014; Wesseldijk et al., 2019), and with results from studies of nonmusicians reporting positive associations between musicality and nonmusical abilities (Correia et al., 2020; Gingras et al., 2015; Mankel & Bidelman, 2018; Morrill et al., 2015; Swaminathan & Schellenberg, 2017). In other words, some musical and nonmusical differences between trained and untrained individuals do not appear to be the sole consequence of formal music lessons, a finding that is relevant to contentious debates about music training and plasticity (Bigand & Tillman, 2022; Sala & Gobet, 2020). This finding also highlights the importance of measuring musical abilities *and* music training in order to tease apart training-specific from more general associations.

Our finding that cognitive ability predicted musical abilities in the absence of formal training extends previous results from individuals who varied widely in training (e.g., Swaminathan et al., 2017, 2018; Swaminathan & Schellenberg, 2018, 2020). Indeed, the magnitude of the association between cognitive and musical *abilities* that we observed was comparable to associations that have been reported between cognitive ability and music *training* (e.g., Degé et al., 2011; Schellenberg, 2006; Swaminathan & Schellenberg, 2018). Perhaps listeners with higher cognitive ability perform better on virtually any test (Carroll, 1993), including music-discrimination tasks such as the MET, which makes them better able to deal with the demands of musical activities and more likely to pursue music training (Mosing et al., 2019). By contrast, and unexpectedly, there was no association between musical ability and openness, even though openness predicts musical ability in studies of musicians (Butkovic et al., 2015; Kuckelkorn et al., 2021; Vincenzi et al., 2022) and individuals who vary in music training (Corrigall et al., 2013; Thomas et al., 2016). Nevertheless, the association between openness and our Music Practice variable suggests that open individuals are more likely to practice and play music actively, whether or not formal training is involved.

Observed associations between musical ability and the Gold-MSI subscales, and between musical ability and untutored Music Practice, highlight the multifaceted nature of musicality. These associations do not appear to be task-specific, because they extend to other ways of measuring musical ability using objective tests and self-reports (Kunert et al., 2016; Law & Zentner, 2012; Lee & Müllensiefen, 2020; Müllensiefen et al., 2014). One possibility is that individual differences in musical behaviors determine musical ability, including low-level discrimination skills. Alternatively, pre-existing levels of musical ability could influence musical behaviors and levels of engagement with music, or a third unidentified variable could be involved. In our view, however, it is more likely that individuals with higher levels of musical ability have an increased probability of practising music informally and engaging with music in various ways, which in turn enhances their ability further—a classic gene-environment correlation, which Scarr and McCartney (1983) called *niche-picking*.

Untutored music practice proved to be a better predictor of performance on the Melody compared to the Rhythm subtest. Other studies that used the MET reported a similar finding with formal music training, which was a better predictor of Melody than of Rhythm (e.g., Swaminathan et al., 2021; Wallentin et al., 2010). In a study of adults (Thomas et al., 2016, Table 1) that used a different music-training variable (number of music classes), training had a stronger association with Melody than with Rhythm scores. Similarly, in a study of children (Ilari et al., 2016), a one-year music program led to greater improvements in the children's ability to discriminate melodies than rhythms. For our sample of untrained participants, however, performance on the Melody and Rhythm subtests was *not* associated with scores on the Active Engagement subscale from the Gold-MSI, which indexes behaviors such as searching the internet for music-related items, commenting about music in posts on social media, and time spent listening attentively to music. In short, strong associations with Melody scores appear to be limited to *active* music playing and practice, regardless of tutoring, learning context, and the player's goals. Perhaps melody processing is more amenable to learning, whereas rhythm is more stable. Swaminathan et al. (2021) speculated that this might be the reason why rhythm is present in the music of all cultures, but melody is not. It is also possible that specific aspects of informal music practice promote melody processing, such as choosing to play the violin rather than the drums.

On the one hand, then, informal music practice among our untrained participants was linked more strongly to performance on the Melody than the Rhythm subtest. On the other hand, high levels of overall musical ability (i.e., MET Total scores) were a consequence of particularly high *Rhythm* scores. In fact, high-ability untrained participants performed similarly to the average trained participant on the Melody subtest, but higher on the Rhythm subtest. When the comparison was restricted to equally high-ability trained participants, the two-way interaction between group and subtest remained strong, with the trained group performing better on Melody, but no group difference on Rhythm. As in Swaminathan et al. (2021), moreover, performance on the Rhythm subtest was more closely linked to cognitive ability. Other findings show that rhythm abilities predict language abilities (Gordon et al., 2015; Lee et al., 2020; Swaminathan & Schellenberg, 2017; Swaminathan & Schellenberg, 2020), and that they are better than melody abilities at predicting *future* musical abilities in general—not just rhythm processing (Kragness et al., 2021). Compared to melody processing, then, rhythm may represent a more fundamental musical ability, which helps to explain further its universality as well as its stability.

As one might expect, our untrained participants—even those with high MET scores—were less likely to play a musical instrument and had lower levels of current music practice compared to trained participants. The untrained group also had lower levels of other musical experiences and skills, as measured by the Gold-MSI. Higher scores on all music-behavior variables were expected because participants with several years of music training would be more likely to engage regularly with a variety of musical activities.

The main limitation of our findings is that we used a single, relatively low-level measure of musical ability, with only two subtests. Thus, our results may not generalize to other tests of musical ability that have additional subtests (Law & Zentner, 2012; Ullén et al., 2014; Zentner & Strauss, 2017). Although the MET has been used widely and correlates with other measures of musical expertise and with music training (e.g., Hansen et al., 2013; Slevc et al., 2016; Swaminathan et al., 2021; Wallentin et al., 2010), future studies could use alternative tests of musical ability, as well as measures that evaluate lower-level abilities such as sound segregation and frequency or temporal discrimination. Additionally, the MET considers missing responses to be incorrect, which could lower scores and/or add noise to the data, particularly in an online study. Nevertheless, missing responses are considered incorrect on many psychological tests with forced-choice judgements, including other tests of musical ability (e.g., Peretz et al., 2003; Ullén et al., 2014; Vuvan et al., 2018), as well as tests of general cognitive ability (e.g., Raven, 1965). Moreover, when Correia et al. (2022) excluded participants with consecutive missing responses on the MET, the test's psychometric properties were not affected negatively.

In our sample, increases in age predicted improved performance on the MET (Table 5.3). Although a pattern of decline could be expected based on the cognitive ageing literature (e.g., Grady, 2012; Salthouse, 2019), age-related trajectories in music perception are not necessarily characterized by a decline (Halpern, 2020). In any event, our sample was less than ideal for testing ageing effects (only 23 participants were over 40 years old, and only eight over 65). We speculate that the positive association with age stems from cumulative exposure to music. Alternatively, many of our younger participants were undergraduate students, who perhaps had less motivation to score well on the MET, compared to older participants who were recruited primarily from the community.

To conclude, the present study provided evidence that predictor variables typically associated with music training also predict musical ability in the absence of training, except for the personality trait openness, which predicted informal music practice but not musical ability. The association between *informal* music practice and performance on the Melody subtest was strong, which implies that such practice should be considered when studying untrained individuals. Regardless, our results confirm that formal music lessons are *not* required to develop good musical abilities, or for associations between musical and nonmusical domains to emerge. Different pathways, namely informal engagement with music and genetic predispositions, appear to play an important role, although many hours of deliberate practice are obviously essential for skilled performance (Ericsson, 2008). In our view, the musicality of untrained participants needs to be considered seriously in order to develop a complete understanding of associations between music training and nonmusical abilities. Musical expertise and musical ability are more than just taking music lessons.

References

Anaya, E. M, Pisoni, D. G., & Kronenberger, W. G. (2017). Visual-spatial sequence learning and memory in trained musicians. *Psychology Of Music*, *45*(1), 5-21. https://doi.org/10.1177/0305735616638942

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods, 52*(1), 388–407. https://doi.org/10.3758/s13428-019-01237-x

Bidelman, G. M., Hutka, S., & Moreno, S. (2013). Tone Language Speakers and Musicians Share Enhanced Perceptual and Cognitive Abilities for Musical Pitch: Evidence for Bidirectionality between the Domains of Language and Music. *Plos ONE*, *8*(4), e60676. https://doi.org/10.1371/journal.pone.0060676

Bigand, E., & Poulin-Charronnat, B. (2006). Are we “experienced listeners?” A review of the musical capacities that do not depend on formal musical training. *Cognition, 100*(1), 100-130. https://doi.org/10.1016/j.cognition.2005.11.007

Bigand, E., & Tillmann, B. (2022). Near and far transfer: Is music special? *Memory & Cognition, 50*(2), 339-347. https://doi.org/10.3758/s13421-021-01226-6

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of music practice: Underlying environmental and genetic influences. *Personality and Individual Differences, 74*, 133-138. https://doi.org/10.1016/j.paid.2014.10.006

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge University Press. https://doi.org/10.1017/CBO9780511571312

Chierchia, G., Fuhrmann, D., Knoll, L. J., Pi-Sunyer, B. P., Sakhardande, A. L., & Blakemore, S. (2019). The matrix reasoning item bank (MaRs-IB): Novel, open-access abstract reasoning items for adolescents and adults. *Royal Society Open Science, 6*(10), Article 190232. https://doi.org/10.1098/rsos.190232

Correia, A. I., Castro, S. L., MacGregor, C., Müllensiefen, D., Schellenberg, E. G., & Lima, C. F. (2020). Enhanced recognition of vocal emotion in individuals with naturally good musical abilities. *Emotion*. Advance online publication. http://dx.doi.org/10.1037/emo0000770

Correia, A. I., Vincenzi, M., Vanzella, P., Pinheiro, A. P., Lima, C. F., & Schellenberg, E. G. (2022). Can musical ability be tested online? *Behavior Research Methods*. Advance online publication. https://doi.org/10.3758/s13428-021-01641-2

Corrigall, K. A., Schellenberg, E. G., & Misura, N. M. (2013). Music training, cognition, and personality. *Frontiers in Psychology, 4*:222. https://doi.org/10.3389/fpsyg.2013.00222

Degé, F. (2021). Music lessons and cognitive abilities in children: How far transfer could be possible. *Frontiers in Psychology, 11*: 557807. https://doi.org/10.3389/fpsyg.2020.557807

Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: A relation mediated by executive functions. *Music Perception, 29*(2), 195–201. https://doi.org/10.1525/mp.2011.29.2.195

Dowling, W. J., Kwak, S., & Andrews, M. W. (1995). The time course of recognition of novel melodies. *Perception & Psychophysics, 57*(2), 136-149. https://doi.org/10.3758/bf03206500

Ericsson, K. A. (2008). Deliberate practice and acquisition of expert performance: A general overview. *Academic Emergency Medicine, 15*(11), 988-994. https://doi.org/10.1111/j.1553-2712.2008.00227.x

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods 39*(2)*,* 175–191. https://doi.org/10.3758/BF03193146

Folkestad, G. (2006). Formal and informal learning situations or practices *vs* formal and informal ways of learning. *British Journal of Music Education*, *23*(2), 135-145. https://doi.org/10.1017/s0265051706006887

Gingras, B., Marin, M. M., Puig-Waldmüller, E., & Fitch, W. T. (2015). The eye is listening: Music-induced arousal and individual differences predict pupillary responses. *Frontiers in Human Neuroscience, 9*:619. https://doi.org/10.3389/fnhum.2015.00619

Gordon, R. L., Shivers, C. M., Wieland, E. A., Kotz, S. A., Yoder, P. J., & McAuley, J. D. (2015). Musical rhythm discrimination explains individual differences in grammar skills in children. *Developmental Science, 1*8(4), 635–644. https://doi.org/10.1111/desc.12230

Grady, C. (2012). The cognitive neuroscience of ageing. *Nature Reviews Neuroscience*, *13*, 491-505. https://doi.org/10.1038/nrn3256

Green, L. (2002). *How popular musicians learn: A way ahead for music education*. Routledge.

Halpern, A. R. (2020). Processing of musical pitch, time, and emotion in older adults. In L. L. Cuddy, S. Belleville, & A. Moussard (Eds.), *Music and the Aging Brain* (pp. 43-67). Academic Press.

Hambrick, D. Z., & Tucker-Drob, E. M. (2015). The genetics of music accomplishment: Evidence for gene–environment correlation and interaction. *Psychonomic Bulletin & Review, 22*(1), 112–120. https:// doi.org/10.3758/s13423-014-0671-9

Hansen, M., Wallentin, M., & Vuust, P. (2013). Working memory and musical competence of musicians and non-musicians. *Psychology of Music, 41*(6), 779-793. https://doi.org/10.1177/0305735612452186

Ilari, B. S., Keller, P., Damasio, H., & Habibi, A. (2016). The development of musical skills of underprivileged children over the course of 1 year: A study in the context of an El Sistema-inspired program. *Frontiers in Psychology, 7*:62. https://doi.org/10.3389/fpsyg.2016.00062

James, C. E., Zuber, S., Dupuis-Lozeron, E., Abdili, L., Gervaise, D., & Kliegel, M. (2020). How Musicality, Cognition and Sensorimotor Skills Relate in Musically Untrained Children. *Swiss Journal of Psychology*, *79*(3-4), 101-112. https://doi.org/10.1024/1421-0185/a000238

Jarosz, A., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting Bayes factors. *Journal of Problem Solving, 7*(1), 2–9. https://doi.org/10.7771/1932-6246.1167

JASP Team (2022). JASP (Version 0.16.1) [Computer software].

Jeffreys, H. (1961). *The theory of probability* (3rd ed.). Oxford University Press.

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). *The Big Five Inventory--Versions 4a and 54*. University of California, Berkeley, Institute of Personality and Social Research.

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big-five Trait taxonomy: History, measurement, and conceptual issues. In O. P. John, R. W. Robins, & L. A. Pervin (Eds.), *Handbook of personality: Theory and research* (pp. 114-158). Guilford Press.

Kragness, H. E., Swaminathan, S., Cirelli, L. K., & Schellenberg, E. G. (2021). Individual differences in musical ability are stable over time in childhood. *Developmental Science, 24*(4), e13081. https://doi.org/10.1111/desc.13081

Kuckelkorn, K. L., de Manzano, O., & Ullén, F. (2021). Musical expertise and personality—differences related to occupational choice and instrument category. *Personality and Individual Differences, 173*:110573. https://doi.org/10.1016/j.paid.2020.110573

Kunert, R., Willems, R. M., & Hagoort, P. (2016). An independent psychometric evaluation of the PROMS measure of music perception skills. *PLoS ONE, 11*(7): e0159103. https://doi.org/10.1371/journal.pone.0159103

Larrouy-Maestri, P., Morsomme, D. Magis, D., & Poeppel, D. (2017). Lay listeners can evaluate the pitch accuracy of operatic voices. *Music Perception, 34*(4), 489-495. https://doi.org/10.1525/mp.2017.34.4.489

Law, L. N. C., & Zentner, M. (2012). Assessing musical abilities objectively: Construction and validation of the Profile of Music Perception Skills. *PLoS ONE,* 7(12): e52508. https://doi.org/10.1371/journal.pone.0052508

Lee, H., & Müllensiefen, D. (2020). The Timbre Perception Test (TPT): A new interactive musical assessment tool to measure timbre perception ability. *Attention, Perception, & Psychophysics, 82*(5), 3658–3675. https://doi.org/10.3758/s13414-020-02058-3

Lee, Y. S., Ahn, S., Holt, R. F., & Schellenberg, E. G. (2020). Rhythm and syntax processing in school-age children. *Developmental Psychology, 56*(9), 1632-1641. https://doi.org/10.1037/dev0000969

Lima, C. F., & Castro, S. L. (2011). Speaking to the trained ear: Musical expertise enhances the recognition of emotional speech prosody. *Emotion, 11*(5), 1021-1031. https://doi.org/10.1037/a0024521

Lima, C. F., Correia, A. I., Müllensiefen, D., & Castro, S. L. (2020). Goldsmiths Musical Sophistication Index (Gold-MSI): Portuguese version and associations with socio-demographic factors, personality and music preferences. *Psychology of Music, 48*(3), 376–388. https://doi.org/10.1177/0305735618801997

MacDonald, J., & Wilbiks, J. M. P. (2021). Undergraduate students with musical training report less conflict in interpersonal relationships. *Psychology of Music*. Advance online publication. https://doi.org/10.1177/03057356211030985

Mankel, K., & Bidelman, G. M. (2018). Inherent auditory skills rather than formal music training shape the neural encoding of speech. *Proceedings of the National Academy of Sciences (USA), 115*(15), 13129-13134. https://doi.org/10.1073/pnas.1811793115

Martins, M., Neves, L., Rodrigues, P., Vasconcelos, O., & Castro, S. L. (2018). Orff-based music training enhances children's manual dexterity and bimanual coordination. *Frontiers in Psychology, 9*:2616. https://doi.org/10.3389/fpsyg.2018.02616

Martins, M., Pinheiro, A. P., & Lima, C. F. (2021). Does music training improve emotion recognition abilities? A critical review. *Emotion Review, 13*(3), 199-210. https://doi.org/10.1177/17540739211022035

McCrae, R. R, & John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of Personality, 60*(2), 175–215. https://doi.org/10.1111/j.1467-6494.1992.tb00970.x

Morrill, T. H., McAuley, J. D., Dilley, L. C., & Hambrick, D. Z. (2015). Individual differences in the perception of melodic contours and pitch-accent timing in speech: Support for domain-generality of pitch processing. *Journal of Experimental Psychology: General, 144*(4), 730–736. https://doi.org/10.1037/xge0000081

Mosing, M. A., Hambrick, D. Z., Ullén, F. (2019). Predicting musical aptitude and achievement: Practice, teaching, and intelligence. *Journal of Expertise, 2*(3), 184-197. https://www.journalofexpertise.org

Mosing, M. A., Madison, G., Pedersen, N. L., Kuja-Halkola, R., & Ullén, F. (2014). Practice does not make perfect: No causal effect of musical practice on musical ability. *Psychological Science, 25*(9), 1795-1803. https://doi.org/10.1177/0956797614541990

Mrazek, M. D., Phillips, D. T., Franklin, M. S., Broadway, J. M., & Schooler, J. W. (2013). Young and restless: Validation of the Mind-Wandering Questionnaire (MWQ) reveals disruptive impact of mind-wandering for youth. *Frontiers in Psychology, 4*: 560. https://doi.org/10.3389/fpsyg.2013.00560

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE, 9*(2): e89642. https://doi.org/10.1371/journal.pone.0089642

Nussenbaum, K., Scheuplein, M., Phaneuf, C. V., Evans, M. D., Hartley, C. A. (2020). Moving developmental research online: Comparing in-lab and web-based studies of model-based reinforcement learning. *Collabra: Psychology, 6*(1): 17213. https://doi.org/10.1525/collabra.17213

Peretz, I., Champod, A. S., & Hyde, K. (2003). Varieties of Musical Disorders. *Annals Of The New York Academy Of Sciences, 999*(1), 58-75. https://doi.org/10.1196/annals.1284.006

Raven, J. C. (1965). *Advance Progressive Matrices, Sets I and II*. Psychological Corporation.

Roden, I., Grube, D., Bongard, S., & Kreutz, G. (2014). Does music training enhance working memory performance? Findings from a quasi-experimental longitudinal study. *Psychology of Music, 42*(2), 284–298. https://doi.org/10.1177/0305735612471239

Sala, G., & Gobet, F. (2020). Cognitive and academic benefits of music training with children: A multilevel meta-analysis. *Memory & Cognition, 48*(8), 1429–1441. https://doi.org/10.3758/s13421-020-01060-2

Salthouse, T. (2019). Trajectories of normal cognitive aging. *Psychology And Aging*, *34*(1), 17-24. https://doi.org/10.1037/pag0000288

Scarr, S., & McCartney, K. (1983). How people make their own environments: A theory of genotype → environment effects. *Child Development, 54*(2), 424-435. https://doi.org/10.2307/1129703

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology, 98*(2), 457-468. https://doi.org/10.1037/0022-0663.98.2.457

Schellenberg, E. G. (2020). Correlation = causation? Music training, psychology, and neuroscience. *Psychology of Aesthetics, Creativity, and the Arts, 14*(4), 475-480. https://doi.org/10.1037/aca0000263

Schellenberg, E. G., Corrigall, K. A., Dys, S. P., & Malti, T. (2015). Group music training and children's prosocial skills. *PLoS ONE, 10*(10):e0141449. http://dx.doi.org/10.1371/journal.pone.0141449

Schellenberg, E. G., & Mankarious, M. (2012). Music training and emotion comprehension in childhood. *Emotion, 12*(5), 887–891. https://doi.org/10.1037/a0027971

Slevc, L. R., Davey, N. S., Buschkuehl, N., & Jaeggi, S. M. (2016). Tuning the mind: Exploring the connections between musical ability and executive functions. *Cognition, 152*, 199-211. https://doi.org/10.1016/j.cognition.2016.03.017

Swaminathan, S., & Kragness, H. E., & Schellenberg, E. G. (2021). The Musical Ear Test: Norms and correlates from a large sample of Canadian undergraduates. *Behavior Research Methods, 53*(5), 2007-2024. https://doi.org/10.3758/s13428-020-01528-8

Swaminathan, S., & Schellenberg, E. G. (2017). Musical competence and phoneme perception in a foreign language. *Psychonomic Bulletin & Review, 24*(6), 1929-1934. http://dx.doi.org/10.3758/s13423-017-1244-5

Swaminathan, S., & Schellenberg, E. G. (2018). Musical competence is predicted by music training, cognitive abilities, and personality. *Scientific Reports, 8*:9223. http://dx.doi.org/10.1038/s41598-018-27571-2

Swaminathan, S., & Schellenberg, E. G. (2020). Musical ability, music training, and language ability in childhood. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 46*(12), 2340-2348. http://dx.doi.org/10.1037/xlm0000798

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude? *Intelligence, 62*, 119-124. http://dx.doi.org/10.1016/j.intell.2017.03.005

Swaminathan, S., Schellenberg, E. G., & Venkatesan, K. (2018). Explaining the association between music training and reading in adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 44*(6), 992-999. http://dx.doi.org/10.1037/xlm0000493

Tan, Y. T., McPherson, G. E., Peretz, I., Berkovic, S. F., & Wilson, S. J. (2014). The genetic basis of music ability. *Frontiers in Psychology, 5*:658. https://doi.org/10.3389/fpsyg.2014.00658

Thomas, K. S., Silvia, P. J., Nusbaum, E. C., Beaty, R. E., & Hodges, D. A. (2016). Openness to experience and auditory discrimination ability in music: An investment approach. *Psychology of Music, 44*(4), 792–801. https://doi.org/10.1177/0305735615592013

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2004). Decoding speech prosody: Do music lessons help? *Emotion, 4*(1), 46-64. https://doi.org/10.1037/1528-3542.4.1.46

Tierney, A., Rosen, S., & Dick, F. (2020). Speech-in-speech perception, nonverbal selective attention, and musical training. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 46*(5), 968–979. https://doi.org/10.1037/xlm0000767

Ullén, F., Mosing, M. A., Holm, L., Eriksson, H., & Madison, G. (2014). Psychometric properties and heritability of a new online test for musicality, the Swedish Musical Discrimination Test. *Personality and Individual Differences, 63*, 87-93. https://doi.org/10.1016/j.paid.2014.01.057

Veblen, K. K. (2012). Adult music learning in formal, informal, and nonformal contexts. In G. E. McPherson & G. F. Welch (Eds.), *The Oxford handbook of music education* (Vol. 2; pp. 243–256). Oxford University Press.

Vincenzi, M., Correia, A. I., Vanzella, P., Pinheiro, A. P., Lima, C. F., & Schellenberg, E. G. (2022). Associations between music training and cognitive abilities: The special case of professional musicians. *Psychology of Aesthetics, Creativity, and the Arts.* Advance online publication. https://doi.org/10.1037/aca0000481

Vuvan, D. T., Paquette, S., Mignault Goulet, G., Royal, I., Felezeu, M., & Peretz, I. (2018). The Montreal Protocol for Identification of Amusia. *Behavior Research Methods*, *50*(2), 662-672. https://doi.org/10.3758/s13428-017-0892-8

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010). The Musical Ear Test, a new reliable test for measuring musical competence. *Learning and Individual Differences, 20*(3), 188-196. https://doi.org/10.1016/j.lindif.2010.02.004

Wan, C. Y., & Schlaug, G. (2010). Music making as a tool for promoting brain plasticity across the lifespan. *The Neuroscientist, 16*(5), 566-577. https://doi.org/10.1177/1073858410377805

Wesseldijk, L. W., Mosing, M. A., & Ullén, F. (2019). Gene–environment interaction in expertise: The importance of childhood environment for musical achievement. *Developmental Psychology, 55*(7), 1473–1479. https://doi.org/10.1037/dev0000726

Zentner, M., & Strauss, H. (2017). Assessing musical ability quickly and objectively: development and validation of the Short-PROMS and the Mini-PROMS. *Annals of the New York Academy of Sciences, 1400*(1), 33-45. ttps://doi.org/10.1111/nyas.13410

Zhang, J. D., Susino, M., McPherson, G. E., & Schubert, E. (2020). The definition of a musician in music psychology: A literature review and the six-year rule. *Psychology Of Music*, *48*(3), 389-409. https://doi.org/10.1177/0305735618804038

CHAPTER 6

Self-awareness of Musical Ability

Correia, A. I., Lima, C. F., & Schellenberg, E. G. (2023). Self-awareness of musical ability. *Psychology of Aesthetics, Creativity, and the Arts*. Advance online publication. https://doi.org/10.1037/aca0000612

Abstract

We asked whether adults have accurate self-awareness of their musical ability, and whether such self-awareness relates to other individual differences. Participants (N = 256) rated how musical they were compared to their friends, colleagues, family, and the general population. They subsequently completed self-report measures of musical behaviors (Goldsmith's Musical Sophistication Index—Gold-MSI) and personality, as well as objective tests of cognitive (matrix reasoning problems) and musical (Musical Ear Test—MET) abilities. Participants considered themselves to be more musical than their colleagues and family but not than their friends and the general population. Correlations with Gold-MSI scores provided evidence for the construct and content validity of the self-ratings. Musicality self-ratings were associated with better performance on the Melody (but not the Rhythm) subtest of the MET, higher levels of openness-to-experience and extraversion, and gender: men rated themselves as particularly musical even though there were no gender differences in objective musical ability. Cognitive ability was not associated with self-ratings although it predicted MET scores and the accuracy of self-ratings. In short, individuals exhibited self-awareness for pitch-based aspects of their musical ability. Their evaluations were associated with their personalities and tended to be exaggerated, however, particularly for men and for participants with lower cognitive ability.

Keywords: music, ability, metacognition, training, personality

6.1. Introduction

Like most human traits, musical ability varies widely across individuals. Although it is tempting to think that musical expertise results from music training and practice (Ericsson et al., 1993; Howe et al., 1998; Schellenberg, 2020), there is a strong genetic component (Hambrick & Tucker-Drob, 2015; Mosing et al., 2014), which is consistent with the concept of musical *aptitude* (i.e., natural musical ability, talent, a good ear). Indeed, when musical ability among typically developing children is measured with music-perception tests, performance is relatively *uninfluenced* by formal music training. Rather, natural ability appears to determine who takes music lessons (Kragness et al., 2021). Consequently, musical ability has become the focus of much research, particularly when it has the potential to explain associations between musical and nonmusical domains that were thought previously to stem from music training, such as general cognitive ability (Mosing et al., 2016; Swaminathan et al., 2017, 2018) and speech or language processing (Bhatara et al., 2015; Correia et al., 2022a; Foncubierta et al., 2020; Mankel et al., 2020; Mankel & Bidelman, 2018; Slevc & Miyake, 2006; Swaminathan & Schellenberg, 2017, 2020).

In the present investigation, we asked whether participants' intuitive self-perceptions of their musical ability relate to their ability measured objectively and with a self-report questionnaire, and whether such self-awareness is associated with other individual differences. These questions have practical and theoretical importance. On a practical level, music is a universal feature of human cultures and a central part of identity formation (Frith, 1996; van der Hoeven, 2018), particularly for young adults in Western societies. For example, when young adults are becoming acquainted, musical preferences are one of the most frequent topics of discussion, presumably because such preferences (and other musical behaviors) reveal much about one's personality (Rentfrow & Gosling, 2006). Thus, if music-related individual differences are central to social interactions, it behooves psychologists to understand them as well as possible.

On a theoretical level (Duvall & Wicklund, 1972; Rochat, 2003), self-awareness of musical ability is one aspect of *metacognition* (Metcalfe & Shimamura, 1994), which refers to knowledge of one's cognitive abilities, as well as the ability to monitor and control cognitive activity. Whereas the latter is related to executive functioning, the former is more self-reflective, referring to individuals' knowledge of their cognitive strengths and weaknesses, both within themselves (e.g., good vocabulary but poor mathematical skills) and compared with others. Rochat (2003) describes self-awareness as "arguably the most fundamental issue in psychology" (p. 717), which develops rapidly from infancy to 5 years of age, yet in adulthood remains as the nexus of communication between different levels of consciousness. Self-awareness differs from self-consciousness, a form of meta self-awareness, when the self is aware of how it is viewed by others (Rochat, 2003).

Self-awareness can be measured by way of the "rouge test" (mirror self-recognition) in infancy (e.g., Amsterdam, 1972), and by tests of theory-of-mind (Baron-Cohen et al., 1985), when by 4 years of age children realize that someone else holds a false belief, self-aware that they know the truth. Later in development, researchers may ask typically developing participants to estimate their ability to remember words (Murphy et al., 2022), or cognitively intact (Schoo et al., 2013) or impaired (Piras et al., 2016) individuals to rate their cognitive abilities. Typically developing individuals tend to overestimate their abilities across cognitive domains (e.g., attention, memory), whereas cognitively impaired individuals become more inaccurate as their impairments are more severe. Metacognitive skills also become more general over the adolescent years, showing greater similarity across domains (van der Stel & Veenman, 2014).

Previous studies of self-awareness of musical ability include an ethnographic analysis of eight children in fourth grade (Shouldice, 2020), and an article that reported four case-studies of adults (Ruddock & Leong, 2005). Other studies focused on musicians' and music students' perceived *self-efficacy* (e.g., Hendricks, 2014; Neilsen, 2004), self-beliefs that are extended to actual behavior in context. In music, self-efficacy refers to people's beliefs in their ability to learn or perform music proficiently (e.g., Gill et al., 2022; McPherson & McCormick, 2006; Ritchie & Williamon, 2007, 2012). Self-efficacy relates to professional experience in adults (Papageorgi et al., 2009), and to music instruction in primary school students (Ritchie & Williamon, 2011). As Bandura's (1977, 1986) theory predicts (Hendricks, 2016; Zelenak, 2020), musicians' and music students' self-efficacy beliefs about their musical skills are also associated with their accomplishments in previous performances (Papageorgi et al., 2009; Zelenak, 2015), feedback and support from others (Gill et al., 2022; Hendricks, 2014; Zarza-Alzugaray et al., 2020), observations and comparisons with other people's performances (Zelenak, 2010), and physiological and emotional responses (e.g., arousal levels, anxiety) evoked by performing music (Zarza-Alzugaray et al., 2020; Zelenak, 2010). Importantly, the quality of musicians' performances is predicted better by their perceived self-efficacy than by duration of music training and/or frequency of practice (McCormick & McPherson, 2003; McPherson & McCormick, 2006; Ritchie & Williamon, 2012). In other words, for musicians and music students, perceived self-efficacy is associated with better performance skills.

The present study differed from earlier reports because we examined self-perceptions of musical ability among adults who were not, for the most part, musicians. One goal was to determine whether the link between self-perceptions and objectively measured ability extends to individuals with minimal or no music training, and therefore minimal performance experience and external feedback. For musically untrained individuals, self-awareness of musical ability is likely to stem primarily from social comparisons and self-evaluations. Thus, at the beginning of the study, our participants made social comparisons, rating how musical they were in relation to their family, friends, colleagues, and the general population. *Musical* was left undefined so that it would not influence or prime responses, and because we were interested in participants' intuitions about musicality.

Comparative self-ratings were collected first so that they would not be affected by the subsequent tests, which included self-report measures of musical behaviors (Goldsmiths Musical Sophistication Index—Gold-MSI, Müllensiefen et al. 2014) and personality, followed by objective tests of general cognitive and musical ability. The test of musical ability—the Musical Ear Test (MET, Wallentin et al., 2010)—required participants to determine whether standard and comparison tone sequences were identical. Such same-different tasks allow the MET and similar tests (Law & Zentner, 2012; Peretz et al., 2013; Ullén et al., 2014) to be administered to musically trained and untrained children and adults. Although these tests do *not* measure all aspects of musical ability, they measure fundamental aspects of music perception objectively, reliably, and validly.

In addition to asking whether self-rated musical ability is associated with objective musical ability, we asked whether self-ratings would be more closely related to performance on one of the MET's two subtests: Melody or Rhythm, which require participants to discriminate sequences that differ in pitch or time, respectively. In previous large-sample studies, music *training* was a better predictor of Melody than of Rhythm scores (Correia et al., 2022b; Swaminathan et al., 2021), possibly because formal training in Western music emphasizes pitch patterns (i.e., melody and harmony) more than temporal patterns (i.e., meter and rhythm). More generally, conceptions of musicality in Western (European and North American) musical cultures also tend to focus more on pitch compared to rhythm, at least before the relatively recent surge in popularity of rap and hip-hop music. Because our sample was recruited in Europe (Portugal), we hypothesized that self-ratings of musicality would also be more closely linked to scores on the Melody compared to the Rhythm subtest.

We included the Gold-MSI (Müllensiefen et al., 2014) primarily to examine the self-ratings' construct validity, and because its assessment of musicality is much broader than that of objective measures. The Gold-MSI is a reliable, valid, and widely used index of musical sophistication, which provides separate scores for five subscales that measure specific abilities and behaviors, including music training, emotional responding, perceptual abilities, singing abilities, and active engagement with music, as well as a general factor (aggregate index) of musical sophistication. Correlations with the general factor would provide evidence for the construct validity of participants' self-ratings, whereas correlations across subtests would provide evidence of their content validity, indicating that self-defined musical ability is commensurate with scholars' concepts of musical expertise. Moreover, differences across subscales in the magnitude of the associations with self-ratings would identify which behaviors are deemed by participants to be the best indicators of musicality. In short, another main objective of the present study was to determine whether participants' intuitive notions of their own musicality would predict the relatively detailed but multifaceted information provided by the Gold-MSI.

One trait from the Big Five model (McCrae & John, 1992; John & Srivastava, 1999)—openness-to-experience (hereafter *openness*)—has positive associations with musical ability, music training, and professional musicianship (Butkovic et al., 2015; Correia et al., 2022b; Corrigall et al., 2013; Kuckelkorn et al., 2021; Swaminathan & Schellenberg, 2018; Vincenzi et al., 2022). It is also correlated positively with all scores provided by the Gold-MSI (Lima et al., 2020). These associations led us to predict that people with higher levels of openness would also consider themselves to be more musical. Extraversion is additionally predictive of being a professional musician (Kuckelkorn et al., 2021; Vincenzi et al., 2022), and of self-reports of musical experiences, including the Gold-MSI general factor and its Active Engagement, Singing Abilities, and Emotions subscales (Lima et al., 2020). Thus, comparative self-ratings of musicality could also be associated with extraversion.

Finally, we expected participants' self-evaluations to exhibit biases that have been observed in other domains, including a general trend for individuals to judge themselves as better than average, and a particular bias among men to over-rate their abilities. The better-than-average effect is highly reliable and refers to individuals' tendency to self-evaluate themselves as above average across many different abilities, attributes, and personality traits (Zell et al., 2020). For example, individuals in the US rate themselves as higher in comparison with the average American on desirable traits such as intelligence, reliability, loyalty, and attractiveness (Ziano et al., 2021). We predicted this bias would also be evident for musical ability in a sample of Portuguese individuals.

The gender bias refers to findings showing that men provide higher self-ratings compared to women in non-musical domains, such as academic ability (Cooper et al., 2018) and job performance (Herbst, 2020). In one study (Exley & Kessler, 2022), participants took a multiple-choice test on science and math and subsequently rated how well they did on the test. Even though there was no gender difference in performance, men provided higher self-ratings compared to women, and this male bias was observed even among 6th-graders. Similar studies of musical ability are scarce with adults, although illusory male advantages have been identified among high-school (Hendricks et al., 2015) and university (Nielsen, 2004) music students. In any event, we predicted that men would provide higher self-ratings compared to women.

Other findings from previous studies (Correia et al., 2022b; Swaminathan et al., 2021; Wallentin et al., 2010) motivated additional predictions about general cognitive ability, which was expected to correlate positively with performance on the MET, and with metacognitive *accuracy*, in the same way that general ability has a positive but moderate association with metacognitive ability in other domains (Ohtani & Hisasaka, 2018). We did not, however, expect cognitive ability to be associated with absolute levels of musicality self-ratings, because typically developing and even high-functioning individuals (e.g., Che Guevara, Ulysses S. Grant) can be atypically unmusical (i.e., as in congenital amusia; Peretz & Vuvan, 2017), whereas low-functioning individuals, such as individuals with Williams Syndrome (IQ: $M \approx 70$; Mervis & Becerra, 2007), can be surprisingly musical (Don et al., 1999; Levitin et al., 2004). In short, we examined self-ratings of musicality, asking whether they reflect objective musical ability, whether they are associated differentially with distinct aspects of musical expertise, and whether they—and their accuracy—are predicted by other individual differences.

6.2. Method

6.2.1. Participants

The study and research protocol were approved by the local ethics committee at Iscte—University Institute of Lisbon (reference 07/2021). All participants provided informed consent. They were 256 Portuguese-speaking adults (195 women, 61 men), who ranged in age from 18 to 66 years (M = 25.0, SD = 9.0, Median/Mode = 22.0), although most were young adults (i.e., 84% were under 30). Participants were recruited without regard to musical background to take part in an online study of musical ability and personality. Feedback about their ability and personality was offered as an incentive. Most participants were friends, acquaintances, and family members of first-year master's students enrolled in an organizational-psychology program. As in many online tests, we sought to recruit as many participants as possible within the time-frame of the study. Post-hoc power analysis conducted with G* Power 3.1 (Faul et al., 2007) confirmed that a sample of 256 participants provided more than a 95% probability of detecting pairwise correlations of 0.1 or greater (α = .05, two-tailed).

Most participants had completed high school (*n* = 142) or obtained an undergraduate degree (*n* = 92). Others had a master's degree (*n* = 2) or had not finished high school (*n* = 2). Women had, in general, more education than men, *p* = .043, such that education was held constant in statistical analyses involving gender. Almost half of the participants (*n* = 117) had no formal training in music, 63 had 2 years or less, and 35 had 2 to 5 years. According to convention, only 41 of 256 (16%) would therefore be classified as *musicians* or *musically trained*, with 6 or more years of lessons (Zhang et al., 2020). Duration of music lessons had no association with gender, age, or education, *p*s > .2.

6.2.2. Materials and Tasks

Online stimulus presentation and data collection were programmed in Gorilla Experiment Builder (Anwyl-Irvine et al., 2020), an online platform for behavioral research. The tests included in this study have good reliability and validity (Correia et al., 2022b) and are freely available on Gorilla (https://app.gorilla.sc/openmaterials/218554).

Musicality Self-Ratings. Participants responded to four questions regarding how musical they were compared with their family, friends, work/school colleagues, and the general population. Responses were made on scales that ranged from 1 (far below average) to 7 (far above average), with 4 indicating average musical ability.

Goldsmiths Musical Sophistication Index (Gold-MSI). The Gold-MSI (Müllensiefen et al., 2014; Portuguese version: Lima et al., 2020) is a 38-item self-report questionnaire that provides five subscales quantifying musical behaviors and experiences: Active Engagement (e.g., *I often read or search the internet for things related to music*, Cronbach's α in the present study = .833), Perceptual Abilities (e.g., *I can tell when people sing or play out of tune*, α = .803), Music Training (e.g., *I have had* _______ *years of formal training on a musical instrument [including voice] during my lifetime*, α = .881), Singing Abilities (e.g., *When I sing, I have no idea whether I'm in tune or not*—reverse coded, α = .771), and Emotions (e.g., *Music can evoke my memories of past people and places*, α = .681). An aggregate General Factor is calculated using items from each subscale (α = .886).

Participants responded using a scale that ranged from 1 (completely agree) to 7 (completely disagree), except for the last seven items, when response alternatives remained on 7-point scales but referred to something other than agreement. For example, for the item that measured duration of regular music lessons (see example above), a score of 1 represented no lessons, 4 represented 2 years, and 7 represented 10 years or more. The Music Training subscale includes items other than years of lessons and regular practice (e.g., music theory, compliments on performances, number of instruments played), but it does not ask for information about when participants started learning or playing music. A 39th open-ended item asks which instrument participants play best.

Big Five Inventory (BFI). The BFI (John & Srivastava, 1999; Portuguese version: Brito-Costa et al., 2015) is a self-report questionnaire commonly used to measure personality traits as described by the five-factor model (McCrae & John, 1992; John & Srivastava, 1999). It has 44 items that participants rate on a scale from 1 (disagree strongly) to 5 (agree strongly). Each rating refers to how much it applies to the participant (e.g., *I am talkative*). The items are grouped and averaged to form the big-five personality traits: Openness (α = .824), Conscientiousness (α = .816), Extraversion (α = .858), Agreeableness (α = .709), and Neuroticism (α = .871).

Matrix Reasoning Item Bank (MaRs-IB). The MaRs-IB (Chierchia et al., 2019) is an online task used to measure abstract nonverbal reasoning as a proxy for general cognitive ability (e.g., Vincenzi et al., 2022; Nussenbaum et al., 2020). It is modeled after Raven's Progressive Matrices test (Raven & Raven, 2003). On each of 80 trials, participants view a matrix with nine cells (3 x 3): eight of them are filled with abstract shapes that vary systematically on four dimensions (color, size, shape, and location), but the cell in the bottom-right position is always empty. Following the sequential logic of the filled cells, participants are asked which of four alternatives fits the missing cell. The task has a fixed duration of 8 min, regardless of the number of trials completed by each participant. Participants are unaware of task duration, but they are told that they must respond to each trial in 30 s or less, otherwise the task automatically proceeds to the next trial. If participants complete all 80 trials in less than 8 min, trials are re-presented in the same order but responses from repeated trials are not recorded (first 20 trials: N = 256, α = .963; first 30: N = 224, α = .983). The score for each participant is the proportion of trials answered correctly, excluding responses provided in less than 250 ms, which we logit-transformed for statistical analyses.

Musical Ear Test (MET). The MET evaluates music-perception abilities (Wallentin et al., 2010), which the test's creators refer to as musical *competence*. It is designed in the tradition of older music-aptitude tests (e.g., Gordon, 1984), with separate subtests for Melody (α = .767) and Rhythm (α = .713). Both subtests have 52 trials. Trials and subtests are presented in a fixed order (Melody then Rhythm). Two additional practice trials are presented at the beginning of each subtest. Feedback is provided for practice trials but not for test trials.

On each trial, participants hear two short sequences of piano tones (Melody) or drumbeats (Rhythm), followed by a brief response window (for Melody, 1500ms; for Rhythm, 1659 to 3230ms). The task is to judge whether the second sequence is identical to the first. On non-identical trials (26 of 52), the second sequence includes at least one changed tone in the Melody subtest, and at least one changed inter-onset interval in the Rhythm subtest. The entire MET has a duration of approximately 20 min (see Swaminathan et al., 2021 for a detailed description of the MET stimuli). Scores for both subtests are calculated as the number of correct responses. Scores for participants with more than 10 missing responses on a subtest, or who scored significantly below chance levels, (Melody, n = 11; Rhythm, n = 11) were not considered in the statistical analyses.

6.2.3. Procedure

Participants completed a single online testing session in *Gorilla*, which lasted approximately 45 min. Before starting the experiment, they were asked to sit in a quiet place, to wear headphones, and to turn off sound notifications on their personal electronic devices. After providing informed consent, they completed the self-report measures in a fixed order (musicality self-ratings, Gold-MSI, BFI), followed by the objective-ability tests (MaRs-IB, MET). After completing the testing session, participants received summary feedback about their personality, musical sophistication, and musical abilities. Ethical considerations precluded feedback about cognitive ability.

6.3. Results

6.3.1. Self-Ratings of Musical Ability

To test for better-than-average effects, one-sample t-tests (two-tailed) compared musicality self-ratings to the midpoint (4) of the four 7-point scales. After correction for multiple (4) tests, the results confirmed that participants judged themselves to be more musical than their family (M = 4.79, SD = 1.33), Cohen's d = .595, and their colleagues (M = 4.37, SD = 1.44), d = .256, *p*s < .001, but not than their friends ($M = 4.22$, $SD = 1.41$), $d = .156$, $p = .054$, or the general population ($M = 3.98$, $SD = 1.40$), $d = -.014$, $p > .9$. A repeated-measures Analysis of Variance (ANOVA) confirmed that ratings varied across the four scales, $F(3, 765) = 44.55$, $p < .001$, partial $\eta^2 = .149$. Despite differences in absolute magnitude, the four self-musicality ratings were inter-correlated, $.541 \leq r\text{s} \leq .798$, *p*s < .001, which motivated formation of an aggregate (average) musicality self-rating score for use in the remaining analyses (Cronbach's $\alpha = .885$). The mean aggregate score was also higher than the scales' mid-point ($M = 4.34$, $SD = 1.20$), $d = .282$, $p < .001$. Aggregate ratings were not correlated with age or education, *p*s ≥ .586.

6.3.2. Gender: Self-Ratings vs. Objective Ability and Gold-MSI Scores

As predicted, aggregate ratings of musicality were higher for men than for women (education held constant), $F(1, 253) = 10.64$, $p = .001$, partial $\eta^2 = .040$, which led us to ask whether gender predicted objective musical ability. A mixed-design ANOVA with MET subtest (Melody, Rhythm) as a repeated measure and gender as a between-subjects variable revealed no main effect of gender, $F(1, 236) = 1.54$, $p = .215$, partial $\eta^2 = .007$. There was a main effect of subtest, with higher scores for Rhythm than for Melody, $F(1, 236) = 14.91$, $p < .001$, partial $\eta^2 = .059$, as in a previous report with a sample recruited and tested similarly (Correia et al., 2022b). There was no two-way interaction, $F < 1$. Melody and Rhythm scores were correlated, $r = .521$, $p < .001$, as in the past (Bhatara et al., 2015; Correia et al., 2022b; Swaminathan et al., 2020; Wallentin et al., 2010, Experiment 3). For the Gold-MSI (education held constant), there was no gender difference on the general factor, $p = .097$, or on any subscale after correcting for five tests (lowest corrected $p > .2$).

6.3.3. Validity of Self-Ratings

All correlations were calculated with gender and education held constant. As shown in Table 6.1, strong positive associations with Gold-MSI general factor and subscales provided evidence for the construct and content validity of the musicality self-ratings. The correlation with the general factor was particularly strong, with approximately half of the variance shared between variables. Comparisons of the magnitude of the associations between self-ratings and the five subscales[5] (corrected for 10 tests) revealed that correlations with Music Training, Singing Abilities, and Perceptual Abilities were stronger than the correlation with Emotions. The

[5] Conducted with Psychometrica (https://www.psychometrica.de/correlation.html).

association between musicality self-ratings and years of music training was also strong and positive, $r = .412$, $p < .001$.

Table 6.1. Partial Correlations Ordered From Strongest to Weakest, Between Aggregate Musicality Self-Ratings and Gold-MSI Scores (Gender and Education Held Constant).

	r	*p*
Gold-MSI Score		
General Factor	.694	< .001
Music Training	.595	< .001
Singing Abilities	.583	< .001
Perceptual Abilities	.566	< .001
Active Engagement	.455	< .001
Emotions	.367	< .001

6.3.4. Other Correlates of Self-Ratings

Our question about whether musical self-awareness was associated with objective musical ability received positive support from a positive correlation with the Melody subtest, $r = .359$, $p < .001$. There was no association with the Rhythm subtest, $r = .066$, $p = .308$, however, and the correlation with Melody was stronger than the correlation with Rhythm, $p < .001$.

Table 6.2. Partial Correlations Between Aggregate Musicality Self-Ratings and Non-Musical Variables (Gender and Education Held Constant).

	r	*p*
Personality		
Openness	.274	< .001
Extraversion	.215	< .001
Conscientiousness	.144	.022
Neuroticism	-.137	.030
Agreeableness	.118	.060
Cognitive Ability		
MaRs-IB	.033	.597

Associations between musicality self-ratings and nonmusical variables are provided in Table 6.2. After correcting for five tests, strong positive associations with personality were evident for openness and extraversion. As expected, there was no correlation between self-perceived musicality and cognitive ability. Cognitive ability was associated positively, however, with performance on the Melody, $r = .269$, and Rhythm, $r = .324$, subtests of the MET, *p*s < .001. To measure meta-cognitive accuracy, we calculated deviation (inaccuracy) scores by subtracting standardized MET Melody scores from standardized self-ratings of musicality, such that positive and negative scores represented over and underestimates, respectively, relative to objectively measured ability. As predicted, a negative but modest association indicated that participants with lower levels of cognitive ability also tended to overestimate their musical ability, $r = -.190$, $p = .003$.

6.3.5. Aggregate Self-Ratings: Multivariate Analysis

Multivariate analysis used structural equation modeling (conducted with JASP) to analyze which variables independently predicted self-ratings of musicality, and whether the model provided a good fit to the data. The method of estimation was maximum likelihood with standard error calculation. The fit of the model was evaluated by way of a chi-square test, with evidence of adequate and good fits provided by confirmatory fit index (CFI) values of .90 and .95, and root-mean-square error of approximation (RMSEA) values of .10 and .60, respectively (Hu & Bentler, 1999).

The model, illustrated in Figure 1, included a latent variable for self-awareness of musical ability, extracted from four indicators (the measured self-ratings). Standardized factor loadings for the latent self-awareness variable ranged from .71 to .90 (*z*s > 11.32, *p*s < .001), indicating that each measured variable was a good indicator of the construct. Measured predictor variables included MET Melody, MET Rhythm, gender (Men = 1, Women = 0), education, openness, and extraversion. (MET Rhythm scores were included because of their theoretical importance.)

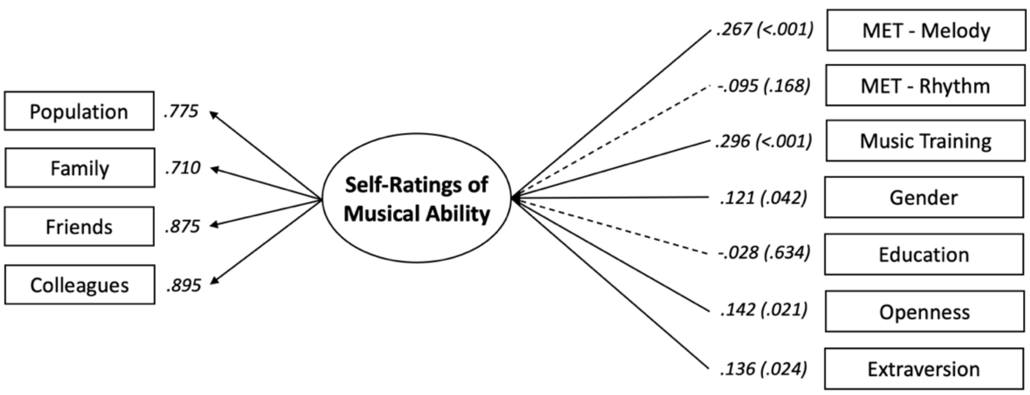

Figure 6.1. Results from a structural equation model used to explain self-awareness of musical ability. The circle represents a latent variable. Rectangles represent measured variables. Indicator and predictor variables are on the left and right, respectively. Numbers on the left indicate factor loadings. Numbers on the right indicate standardized slopes (*p*-values in parentheses). Higher self-ratings were evident among participants with higher MET-Melody scores and more years of music lessons, men, and individuals with higher scores on the personality traits openness-to-experience and extraversion.

The model provided a good fit to the data, $\chi^2(23, N = 238) = 40.958$, $p = .012$, CFI = .972, RMSEA = .057, P (rmsea ≤ 0.05 = .310). All modification indices were below 5.0, which suggests that covariance among error terms was not substantial. All associations reported earlier remained significant (see Figure 1). Self-awareness was associated positively with MET Melody (but not MET Rhythm), duration of music training, gender (but not education), openness, and extraversion, even with all other predictors held constant.

6.4. Discussion

We examined whether participants had accurate awareness of their musical ability, and whether such self-awareness was associated with other individual differences. Self-ratings of musicality were not associated with age, education, or general cognitive ability. Participants considered themselves to be above-average musically compared to their family and colleagues, but similar to their friends and the general population. Overestimates were also greater among men than women, and among individuals with lower cognitive abilities. Nevertheless, self-ratings of musicality correlated positively with self-reports collected by an established index of musical sophistication (Gold-MSI), and with performance on an objective test of melody perception and discrimination (MET-Melody). These findings suggest that individuals are indeed self-aware of some aspects of their musical ability. Musicality estimates were also correlated with openness and extraversion, the same personality traits that predict performance on the Gold-MSI (Lima et al., 2020).

The main finding of the present study was that self-ratings of musicality were positively correlated with all Gold-MSI scores and with MET-Melody scores. Whereas the Gold-MSI measures musical expertise by way of 38 self-report items, the MET indexes musical ability objectively by way of a same-different discrimination task. Both measures have good psychometric properties (Lima et al., 2020; Müllensiefen et al., 2014; Swaminathan et al., 2021; Wallentin et al., 2010). Strong positive correlations with the Gold-MSI subscales and general factor provided evidence for the validity of our self-reports of musical ability. Individual differences in self-ratings, based on participant's intuitive notions of musicality, were correlated positively with aggregate musical-sophistication scores, as well as with the degree to which participants were actively engaged in music, self-reported music-perception abilities, their history of studying and playing music, self-reported singing abilities, and their emotional responses to music. In other words, self-ratings appeared to stem from broad conceptions of musicality, commensurate with scholars' conceptions, at least with those of Müllensiefen and colleagues (2014). Correlations were stronger for the Music Training, Perceptual Abilities, and Singing Abilities subscales than for the Emotions subscale, which suggests that intuitive notions of musicality are based more on the ability to perceive and perform music than they are on simply responding emotionally to music. After all, individuals with low levels of musical ability could still love music passionately.

The correlation with MET-Melody scores provided evidence that associations with Gold-MSI scores were not merely reflective of individual differences in participants' self-esteem or social desirability, or other biases that can emerge in self-reports. Rather, self-ratings were also correlated with the relatively low-level perceptual abilities that are needed to determine whether one tone from a standard sequence is mistuned by as little as a semitone in a comparison sequence. Over years of musical experiences in social settings (e.g., singing *Happy Birthday* at a party, dancing at a club), our participants were likely to learn that some people are more musical than others (e.g., better singers or dancers), and, consequently, where they fit in the scheme of things, at least to some degree. The ability to judge one's own musical abilities accurately has practical implications. Inaccurate high or low estimations of self-ability could speciously encourage or discourage individuals, respectively, to engage in music-related activities, only to end up disgruntled, which might, in turn, negatively impact their self-concepts beyond musical expertise. To date, however, attempts to improve the accuracy of musical self-evaluations have not been particularly successful (Hewitt, 2010).

Although self-perceptions of musicality were associated positively with Melody scores, even after accounting for gender, education, and personality, they were *not* associated with Rhythm scores. These results do not prove the null hypothesis, but if there truly is an association between self-perceptions and Rhythm, it is unlikely to be strong. As noted, differential response patterns for Melody and Rhythm mirrored those from large-sample studies that examined associations between music *training* and MET performance, either with in-person testing and English-speaking participants (Swaminathan et al., 2021), or online testing and romance-language speakers (i.e., from Italy, Portugal, Brazil; Correia et al., 2022b). In any event, we now know that the ability to discriminate melodies is associated positively with participants' intuitive notions of their own musicality, as it is with music training, speaking a tone language (Swaminathan et al., 2018, 2021), and other musical experiences and behaviors (Correia et al., 2022b). In principle, sampling bias could be implicated in the present results, although one would expect the present study to appeal more to musically capable than incapable participants. In other words, sampling error is more likely to explain over-estimates of musical ability, than it would a correlation with Melody but not with Rhythm.

In general, rhythm perception appears to be relatively independent of experiential factors but more strongly linked with stable *nonmusical* variables, such as general cognitive ability (Correia et al., 2022b; Swaminathan et al., 2021), as well as language ability, including speech perception, grammar, and second-language ability (e.g., Bhatara et al., 2015; Gordon et al., 2015; Swaminathan & Schellenberg, 2017, 2020). Perhaps an association between self-ratings of musical ability and rhythm would emerge in musical cultures that place stronger emphasis on temporal dimensions (e.g., African drum music). One might also speculate that rhythm ability—and temporal perception more generally—is more hard-wired than melody ability, yet results from twin studies indicate that genetic contributions to melody and rhythm abilities are similar (Mosing et al., 2014). Future research could attempt to clarify these issues by including multiple measures of melody and rhythm ability, ideally administered longitudinally and with samples of participants recruited from different musical cultures and age groups.

Our evidence for the better-than-average effect is consistent with other comparative evaluations (Zell et al., 2020). But why was this effect evident in comparisons with family and colleagues, and not with friends and the general population? According to Social Comparison Theory (Festinger, 1954), individuals have an instinctive drive to judge their experiences and abilities by comparing themselves with others, especially when such abilities are difficult to evaluate objectively. Moreover, *downward comparisons* (considering others inferior) allow individuals to enhance their self-esteem and well-being (Wills, 1981). For musicians, social comparisons inform self-evaluations of performance (Denton & Chaplin, 2016). For our sample of mostly young-adult nonmusicians, comparisons with family were likely to involve consideration of parents, often deemed *uncool* in a general sense but particularly when music is involved. Colleagues, known but unlikely to be close friends, would have been of similar age to our participants but with varying musical tastes that mark their identities and personalities (Rentfrow & Gosling, 2006). In both instances, downward comparisons may have provided an easy, perhaps automatic means of enhancing self-efficacy and self-confidence (Bandura, 1977). Comparisons with the general population and friends differed because they involved total strangers and familiar peers, respectively. For the general population, it is unlikely that participants envisioned an "average person" that allowed for comparisons with the self, either downward or upward. Friends, by contrast, would likely involve in-group comparisons of individuals with equivalent status, at least on average.

As expected, men overestimated their musical abilities compared to women, although there was no gender difference in terms of objectively measured ability, or on the Gold-MSI general factor or any of its subscales. The comparative aspect of our music-ability questions may have increased the likelihood of a gender difference for our self-ratings, in contrast to the Gold-MSI, for which each item was evaluated absolutely in relation to the self (e.g., *I can tell when people sing or play out of time with the beat*). In a previous study, the gender gap in self-ratings was evident for a male-typed (math and science) task across a variety of contexts, yet it disappeared when the test involved a female-typed task that measured verbal skills (Exley & Kessler, 2020). Perhaps music is still considered to be a male-typed domain, as it has been historically (e.g., the Renaissance, Baroque, Classical, and Romantic eras), despite the abundance of women who are currently successful singers, musicians, and composers.

Self-ratings of musical abilities were associated with the personality traits openness and extraversion, but not with cognitive ability. As levels of openness and/or extraversion increased, so did self-ratings of musical ability. Open and extraverted individuals are likely to be comfortable exhibiting signs of their musical abilities in social situations, which would enhance comparisons with others. Although music training is associated more consistently with openness than it is with extraversion, correlations between Gold-MSI scores and both openness and extraversion were evident in an earlier study conducted in Portugal (Lima et al., 2020). Thus, associations between self-ratings of musicality and Gold-MSI scores appear to extend to *correlates* of the Gold-MSI. Regardless, associations with other predictor variables (gender, MET Melody, duration of music training) remained evident even after accounting for individual differences in openness and extraversion (see Figure 1).

Some limitations of the present study should be acknowledged. One is that we used a comparative measure of self-awareness: Participants judged their ability in comparison with others, which could be influenced by several factors (e.g., having musicians in the family, personality). Another is that objective musical ability was measured with a single test. In other words, future research is needed to confirm that the present findings are not measurement specific. Participants were also offered feedback about their musical ability as an incentive to participate, which may have skewed the sample by making it particularly appealing to those who had positive impressions about their own ability before agreeing to participate. Moreover, participants were acquaintances of master's students in psychology and may not be representative of the general population. Our self-ratings were also holistic—with musicality left undefined—which raises the possibility that different findings could emerge if participants were asked about more specific aspects of their musical ability. Finally, it would be interesting to explore the development of musical self-awareness, as well as motivations behind individuals' self-ratings of musicality (e.g., observations of music performances, feedback from friends or family, personal experiences), which are known to play a role in musicians' and music students' self-efficacy concepts (Hendricks, 2016; Zelenak, 2020).

To conclude, our participants demonstrated self-awareness of their musical abilities that was commensurate with an established self-report measure of musical sophistication as well as with objectively measured abilities, provided these were pitch-based (Melody scores) rather than time-based (Rhythm scores). Self-ratings were not explained by cognitive ability, but they were associated with the personality traits openness and extraversion. They also tended to be exaggerated in general, and in particular by men and by participants with lower levels of cognitive ability. Future studies of musical self-awareness could ultimately improve our understanding of metacognitive abilities in general, and how they relate to the development of musical ability.

References

Amsterdam, B. (1972). Mirror self-image reactions before age two. *Developmental Psychobiology, 5*(4), 297-305. https://doi.org/10.1002/dev.420050403

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods, 52*(1), 388–407. https://doi.org/10.3758/s13428-019-01237-x

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191–215. https://doi.org/10.1037/0033-295X.84.2.191

Bandura, A. (1986). *Social foundations of thought and action*. Prentice-Hall.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition, 21*(1), 37-46. https://doi.org/10.1016/0010-0277(85)90022-8.

Bhatara, A., Yeung, H. H., & Nazzi, T. (2015). Foreign language learning in French speakers is associated with rhythm perception, but not with melody perception. *Journal of Experimental Psychology: Human Perception and Performance, 41*(2), 277–282. https://doi.org/10.1037/a0038736

Brito-Costa, S., Bem-Haja, P., Moisão, A., Alberty, A., Castro, F. V., & De Almeida, H. (2015). Psychometric properties of Portuguese version of Big Five Inventory (BFI). *International Journal of Developmental and Educational Psychology* [*INFAD Revista de Psicología*], *1*(2), 83-94. http://dx.doi.org/10.17060/ijodaep.2015.n2.v1.325

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of music practice: Underlying environmental and genetic influences. *Personality and Individual Differences, 74*, 133–138. https://doi.org/10.1016/j.paid.2014.10.006

Chierchia, G., Fuhrmann, D., Knoll, L. J., Pi-Sunyer, B. P., Sakhardande, A. L., & Blakemore, S. (2019). The matrix reasoning item bank (MaRs-IB): Novel, open-access abstract reasoning items for adolescents and adults. *Royal Society Open Science, 6*(10): 190232. https://doi.org/10.1098/rsos.190232

Cooper, K. M., Kreig, A., & Brownell, S. E. (2018). Who perceives they are smarter? Exploring the influence of student characteristics on student academic self-concept in physiology. *Advances in Physiology Education, 42*(2), 200-208. https://doi.org/10.1152/advan.00085.2017

Correia, A. I., Castro, S. L., MacGregor, C., Müllensiefen, D., Schellenberg, E. G., & Lima, C. F. (2022a). Enhanced recognition of vocal emotion in individuals with naturally good musical abilities. *Emotion, 22*(5), 894-906. http://dx.doi.org/10.1037/emo0000770

Correia, A. I., Vincenzi, M., Vanzella, P., Pinheiro, A., Lima, C. F., & Schellenberg, E. G. (2022b). Can musical ability be tested online? *Behavior Research Methods, 54*(2), 955-969. https://doi.org/10.3758/s13428-021-01641-2

Corrigall, K. A., Schellenberg, E. G., & Misura, N. M. (2013). Music training, cognition, and personality. *Frontiers in Psychology, 4*: 222. https://doi.org/10.3389/fpsyg.2013.00222

Denton, E.-g., & Chaplin, W. F. (2016). How do musicians evaluate their musical performances? The impact of positive and negative information from normative, ipsative, and expectation standards. *Psychology of Music, 44*(3), 399-412. https://doi.org/10.1177/0305735614568883

Don, A. J., Schellenberg, E. G., & Rourke, B. P. (1999). Music and language skills of children with Williams syndrome. *Child Neuropsychology, 5*(3), 154-170. https://doi.org/10.1076/chin.5.3.154.7337

Duval, S., & Wicklund, R. A. (1972). *A theory of objective self awareness*. Academic Press.

Ericsson, K. A., Krampe, R. T., and Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363–406. https://doi.org/10.1037/0033-295X.87.3.215

Exley, C. L., & Kessler, J. B. (2022). The gender gap in self-promotion. *Quarterly Journal of Economics, 137*(3), 1345-1381. https://doi.org/10.1093/qje/qjac003

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods 39*(2)*,* 175–191. https://doi.org/10.3758/BF03193146

Festinger, L. (1954). A theory of social comparison processes. *Human Relations, 7*(2), 117–140. https://doi.org/10.1177/001872675400700202

Foncubierta, J. M., Machancoses, F. H., Buyse, K., & Fonseca-Mora, M. C. (2020). The acoustic dimension of reading: Does musical aptitude affect silent reading fluency? *Frontiers in Neuroscience, 14*:399. https://doi.org/10.3389/fnins.2020.00399

Frith, S. (1996). Music and identity. In S. Hall & P. du Gay (Eds.), *Questions of cultural identity* (pp. 108-128). Sage.

Gill, A., Osborne, M., & McPherson, G. (2022). Sources of self-efficacy in class and studio music lessons. *Research Studies in Music Education*. Advance online publication. https://doi.org/10.1177/1321103X221123234

Gordon, E. (1984). A longitudinal predictive validity study of the Intermediate Measures of Music Audiation. *Bulletin of the Council for Research in Music Education, 78,* 1-23. https://www.jstor.org/stable/40317839

Gordon, R. L., Shivers, C. M., Wieland, E. A., Kotz, S. A., Youder, P. J., & McAuley, J. D. (2015). Musical rhythm discrimination explains individual differences in grammar skills in children. *Developmental Science, 18*(4), 635-644. https://doi.org/10.1111/desc.12230

Hambrick, D. Z., & Tucker-Drob, E. M. (2015). The genetics of music accomplishment: Evidence for gene–environment correlation and interaction. *Psychonomic Bulletin & Review, 22*(1), 112–120. https:// doi.org/10.3758/s13423-014-0671-9

Hendricks, K. S. (2016). The sources of self-efficacy: Education research and implications for music. *Update: Applications of Research in Music Education, 35*(1), 32-38. https://doi.org/10.1177/8755123315576535

Hendricks, K. S. (2014). Changes in self-efficacy beliefs over time: Contextual influences of gender, rank-based placement, and social support in a competitive orchestra environment. *Psychology of Music, 42*(3), 347-365. https://doi.org/10.1177/0305735612471238

Hendricks, K. S., Smith, T. D., & Legutki, A. R. (2015). Competitive comparison in music: influences upon self-efficacy beliefs by gender. *Gender and Education*, *28*(7), 918-934. https://doi.org/10.1080/09540253.2015.1107032

Herbst, T. H. H. (2020). Gender differences in self-perception accuracy: The trust gap and the underrepresentation of women leaders in academia. *SA Journal of Industrial Psychology, 46*(1), 1-8. https://doi.org/10.4102/sajip.v46i0.1704

Hewitt, M. P. (2010). The impact of self-evaluation instruction on student self-evaluation, music performance, and self-evaluation accuracy. *Journal of Research in Music Education*, *59*(1), 6-20. https://doi.org/10.1177/0022429410391541

Howe, M. J., Davidson, J. W., & Sloboda, J. A. (1998). Innate talents: Reality or myth? *Behavioral and Brain Sciences, 21*(3), 399-407. https://doi.org/10.1017/S0140525X9800123X

JASP Team (2022). *JASP* (Version 0.16.3) [Computer software].

John, O. P., & Srivastava, S. (1999). The Big Five trait taxonomy: History, measurement, and theoretical perspectives. In L. A. Pervin & O. P. John (Eds.), *Handbook of personality: Theory and research* (pp. 102–138). Guilford Press.

Kawase, S., Ogawa, J., Obata, S., & Hirano, T. (2018). An investigation into the relationship between onset age of musical lessons and levels of sociability in childhood. *Frontiers in Psychology, 9*, 2244. https://doi.org/10.3389/fpsyg.2018.02244

Kragness, H. E., Swaminathan, S., Cirelli, L. K., & Schellenberg, E. G. (2021). Individual differences in musical ability are stable over time in childhood. *Developmental Science*. Advance online publication. https://doi.org/10.1111/desc.13081

Kuckelkorn, K. L., de Manzano, O., & Ullén, F. (2021). Musical expertise and personality—differences related to occupational choice and instrument category. *Personality and Individual Differences, 173*: 110573. https://doi.org/10.1016/j.paid.2020.110573

Larrouy-Maestri, P., Wang, X., Nunes, R. V., & Poeppel, D. (2021). Are you your own best judge? On the self-evaluation of singing. *Journal Of Voice.* Advance Online Publication. https://doi.org/10.1016/j.jvoice.2021.03.028

Law, L. N. C., & Zentner, M. (2012). Assessing musical abilities objectively: Construction and validation of the Profile of Music Perception Skills. *PLoS ONE, 7*(12): e52508. https://doi.org/10.1371/journal.pone.0052508

Lee, M. D., & Wagenmakers, E.-J. (2014). *Bayesian cognitive modeling: A practical course.* Cambridge University Press.

Levitin, D. J., Cole, K., Chiles, M., Lai, Z., Lincoln, A., & Bellugi, U. (2004). Characterizing the musical phenotype in individuals with Williams Syndrome. *Child Neuropsychology, 10*(4), 223-247. https://doi.org/10.1080/09297040490909288

Lima, C. F., Correia, A. I., Müllensiefen, D., & Castro, S. L. (2020). Goldsmiths Musical Sophistication Index (Gold-MSI): Portuguese version and associations with socio-demographic factors, personality and music preferences. *Psychology of Music, 48*(3), 376–388. https://doi.org/10.1177/0305735618801997

Mankel, K., Barber, J., & Bidelman, G. M. (2020). Auditory categorical processing for speech is modulated by inherent musical listening skills. *NeuroReport, 31*(2), 162-166. https://doi.org/10.1097/WNR.0000000000001369

Mankel, K., & Bidelman, G. M. (2018). Inherent auditory skills rather than formal music training shape the neural encoding of speech. *Proceeding of the National Academy of Sciences USA, 115*(51), 13129–13134. https://doi.org/10.1073/pnas.1811793115

McCormick, J., & McPherson, G. (2003). The role of self-efficacy in a musical performance examination: An exploratory structural equation analysis. *Psychology of Music, 31*(1), 37-51. https://doi.org/10.1177/0305735603031001322

McCrae, R. R, & John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of Personality, 60*(2), 175–215. https://doi.org/10.1111/j.1467-6494.1992.tb00970.x

McPherson, G. E., & McCormick, J. (2006). Self-efficacy and music performance. *Psychology of music*, *34*(3), 322-336. https://doi.org/10.1177/0305735606064841

Mervis, C. B., & Becerra, A. M. (2007). Language and communicative development in Williams syndrome. *Mental Retardation and Developmental Disabilities Research Reviews, 13*(1), 3-15. https://doi.org/10.1002/mrdd.20140

Metcalfe, J., & Shimamura, A. P. (1994). *Metacognition: Knowing about knowing*. MIT Press.

Mori, K., & Iwanaga, M. (2017). Two types of peak emotional responses to music: The psychophysiology of chills and tears. *Scientific Reports, 7*, 46063. https://doi.org/10.1038/srep46063

Mosing, M. A., Madison, G., Pedersen, N. L., Kuja-Halkola, R., & Ullén, F. (2014). Practice does not make perfect: No causal effect of music practice on music ability. *Psychological Science, 25*(9), 1795–1803. https://doi.org/10.1177/0956797614541990

Mosing, M. A., Madison, G., Pedersen, N. L., & Ullén, F. (2016). Investigating cognitive transfer within the framework of music practice: Genetic pleiotropy rather than causality. *Developmental Science, 19*(3), 504–512. https://doi.org/10.1111/desc.12306

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE, 9*(2): e89642. https://doi.org/10.1371/journal.pone.0089642

Murphy, D. H., Huckins, S. C., Rhodes, M. G., & Castel, A. D. (2022). The effect of perceptual processing fluency and value on metacognition and remembering. *Psychonomic Bulletin & Review, 29*(3), 910-921. https://doi.org/10.3758/s13423-021-02030-8

Nielsen, S. G. (2004). Strategies and self-efficacy beliefs in instrumental and vocal individual practice: A study of students in higher music education. *Psychology of Music, 32*(4), 418-431. https://doi.org/10.1177/0305735604046099

Nussenbaum, K., Scheuplein, M., Phaneuf, C. V., Evans, M. D., Hartley, C. A. (2020). Moving developmental research online: Comparing in-lab and web-based studies of model-based reinforcement learning. *Collabra: Psychology, 6*(1): 17213. https://doi.org/10.1525/collabra.17213

Ohtani, K., & Hisasaka, T. (2018). Beyond intelligence: a meta-analytic review of the relationship among metacognition, intelligence, and academic performance. *Metacognition And Learning*, *13*(2), 179-212. https://doi.org/10.1007/s11409-018-9183-8

Papageorgi, I., Creech, A., Haddon, E., Morton, F., De Bezenac, C., Himonides, E., Potter, J., Duffy, C., Whyton, T., & Welch, G. (2009). Perceptions and predictions of expertise in advanced musical learners. *Psychology of Music*, *38*(1), 31-66. https://doi.org/10.1177/0305735609336044

Peretz, I., Gosselin, N., Nan, Y., Caron-Caplette, E., Trehub, S. E., & Béland, R. (2013). A novel tool for evaluating children's musical abilities across age and culture. *Frontiers in Systems Neuroscience*, 7:30. https://doi.org/10.3389/fnsys.2013.00030

Peretz, I., & Vuvan, D. T. (2017). Prevalence of congenital amusia. *European Journal of Human Genetics, 25*(5), 625-630. https://doi.org/10.1038/ejhg.2017.15

Piras, F., Piras, F., Orfei, M. D., Caltagirone, C., & Spalletta, G. (2016). Self-awareness in Mild Cognitive Impairment: Quantitative evidence from systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews, 61*, 90-107. https://doi.org/10.1016/j.neubiorev.2015.10.002

Raven, J., & Raven, J. (2003). Raven Progressive Matrices. In R. S. McCallum (Ed.), *Handbook of nonverbal assessment* (pp. 223–237). Kluwer Academic/Plenum Publishers. https://doi.org/10.1007/978-1-4615-0153-4_11

Rentfrow, P. J., & Gosling, S. D. (2006). Message in a ballad: The role of music preferences in interpersonal perception. *Psychological Science, 17*(3), 236-242. https://doi.org/10.1111/j.1467-9280.2006.01691.x

Ritchie, L., & Williamon, A. (2007). Measuring self-efficacy in music. *Proceedings of the International Symposium on Performance Science 2007*, 307-312. https://researchonline.rcm.ac.uk/id/eprint/376

Ritchie, L., & Williamon, A. (2011). Primary school children's self-efficacy for music learning. *Journal of Research in Music Education*, *59*(2), 146-161. https://doi.org/10.1177/0022429411405214

Ritchie, L., & Williamon, A. (2012). Self-efficacy as a predictor of musical performance quality. *Psychology of Aesthetics, Creativity, and the Arts*, *6*(4), 334. https://doi.org/10.1037/a0029619

Rochat, P. (2003). Five levels of self-awareness as they unfold early in life. *Consciousness and Cognition, 12*(4), 717–731. https://doi.org/10.1016/S1053-8100(03)00081-3

Ruddock, E., & Leong, S. (2005). 'I am unmusical!': The verdict of self-judgement. *International Journal of Music Education, 23*(1), 9-22. https://doi.org/10.1177/0255761405050927

Schellenberg, E. G. (2020). Correlation = causation? Music training, psychology, and neuroscience. *Psychology of Aesthetics, Creativity, and the Arts, 14*(4), 475–480. https://doi.org/10.1037/aca0000263

Schoo, L. A., van Zandvoort, M. J. E., Biessels, G. J., Kappelle, L. J., & Postma, A. (2013). Insight in Cognition: Self-Awareness of Performance Across Cognitive Domains. *Applied Neuropsychology: Adult, 20*(2), 95-102. https://doi.org/10.1080/09084282.2012.670144

Shouldice, H. N. (2020). An investigation of musical ability beliefs and self-concept among fourth-grade students in the United States. *International Journal of Music Education, 38*(4), 525-536. https://doi.org/10.1177/0255761420914667

Slevc, L. R., & Miyake, A. (2006). Individual differences in second-language proficiency: Does musical ability matter? *Psychological Science, 17*(8), 675-681. https://doi.org/10.1111/j.1467-9280.2006.01765.x

Swaminathan, S., Kragness, H. E., & Schellenberg, E. G. (2021). The Musical Ear Test: Norms and correlates from a large sample of Canadian undergraduates. *Behavior Research Methods.* Advance online publication. https://doi.org/10.3758/s13428-020-01528-8

Swaminathan, S., & Schellenberg, E. G. (2017). Musical competence and phoneme perception in a foreign language. *Psychonomic Bulletin & Review, 24*(6), 1929-1934. http://dx.doi.org/10.3758/s13423-017-1244-5

Swaminathan, S., & Schellenberg, E. G. (2018). Musical competence is predicted by music training, cognitive abilities, and personality. *Scientific Reports, 8*: 9223. http://dx.doi.org/10.1038/s41598-018-27571-2

Swaminathan, S., & Schellenberg, E. G. (2020). Musical ability, music training, and language ability in childhood. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 46*(12), 2340-2348. http://dx.doi.org/10.1037/xlm0000798

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude? *Intelligence, 62*, 119-124. http://dx.doi.org/10.1016/j.intell.2017.03.005

Swaminathan, S., Schellenberg, E. G., & Venkatesan, K. (2018). Explaining the association between music training and reading in adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 44*(6), 992-999. http://dx.doi.org/10.1037/xlm000049

Ullén, F., Mosing, M. A., Holm, L., Eriksson, H., & Madison, G. (2014). Psychometric properties and heritability of a new online test for musicality, the Swedish Musical Discrimination Test. *Personality and Individual Differences, 63*, 87-93. https://doi.org/10.1016/j.paid.2014.01.057

van der Hoeven, A. (2018). Narratives of popular music heritage and cultural identity: The affordances and constraints of popular music memories. *European Journal of Cultural Studies*, *21*(2), 207-222. https://doi.org/10.1177/1367549415609328 van der Stel, M., & Veenman, M. V. J. (2014). Metacognitive skills and intellectual ability of young adolescents: A longitudinal study from a developmental perspective. *European Journal of Psychology of Education*, *29*(1), 117-137. https://doi.org/10.1007/s10212-013-0190-5

Vincenzi, M., Correia, A. I., Vanzella, P., Pinheiro, A. P., Lima, C. F., & Schellenberg, E. G. (2022). Associations between music training and cognitive abilities: The special case of professional musicians. *Psychology of Aesthetics, Creativity, and the Arts*. Advance online publication. http://dx.doi.org/10.1037/aca0000481

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010). The Musical Ear Test, a new reliable test for measuring musical competence. *Learning and Individual Differences, 20*(3), 188–196. https://doi.org/10.1016/j.lindif.2010.02.004

Wills, T. A. (1981). Downward comparison principles in social psychology. *Psychological Bulletin, 90*(2), 245–271. https://doi.org/10.1037/0033-2909.90.2.245

Zarza-Alzugaray, F. J., Casanova, O., McPherson, G. E., & Orejudo, S. (2020). Music self-efficacy for performance: An explanatory model based on social support. *Frontiers in Psychology,11*:1249. https://doi.org/10.3389/fpsyg.2020.01249

Zelenak, M. S. (2010). Development and validation of the music performance self-efficacy scale. *Music Education Research International, 4,* 31-43.

Zelenak, M. S. (2015). Measuring the sources of self- efficacy among secondary school music students. *Journal of Research in Music Education, 62*(4), 389-404. https://doi.org/10.1177/0022429414555018

Zelenak, M. S. (2020). Developing self-efficacy to improve music achievement. *Music Educators Journal, 107*(2), 42-50. https://doi.org/10.1177/0027432120950812

Zell, E., Strickhouser, J. E., Sedikides, C., & Alicke, M. D. (2020). The better-than-average effect in comparative self-evaluation: A comprehensive review and meta-analysis. *Psychological Bulletin, 146*(2), 118–149. https://doi.org/10.1037/bul0000218

Zhang, J. D., Susino, M., McPherson, G. E., & Schubert, E. (2020). The definition of a musician in music psychology: A literature review and the six-year rule. *Psychology of Music, 48*(3), 389–409. https://doi.org/10.1177/0305735618804038

Ziano, I., Mok, P. Y., & Feldman, G. (2021). Replication and extension of Alicke (1985) better-than-average effect for desirable and controllable traits. *Social Psychological and Personality Science, 12*(6), 1005-1017. https://doi.org/10.1177/1948550620948973

CHAPTER 7

General Discussion

The woods would be very silent if no birds sang there except those that sang best.

Henry Van Dyke

Although musical abilities have traditionally been linked to musicians, the general population also varies widely in this regard. The main goal of this thesis was to understand individual differences in musicality, or musical ability, among musically trained and untrained individuals. Most previous studies examined group differences between individuals with and without music training. This thesis, by contrast, focused on two key distinctions that tend to be neglected in the literature, namely between professional musicians and other musically trained individuals, and among musically untrained individuals with high or low levels of musical abilities.

7.1. Overview of the Results

Through a series of five studies, we attempted to shed light on two essential questions. First, we asked whether training is the best explanation of previously reported associations between music training and nonmusical abilities, particularly cognitive and socioemotional skills. Second, we sought to identify correlates of musical ability among individuals with no music training.

The first study examined whether high levels of musical expertise are associated with the ability to recognize emotions in vocal and facial expressions. The focus was on links between formal music training and emotion recognition, and whether individuals with no formal music lessons but good musical abilities also show enhanced performance on tests of emotion recognition. The results revealed that musically trained individuals were better at recognizing emotions conveyed through speech prosody and nonverbal vocalizations, but not through facial expressions. These response patterns confirmed the previously found advantage of musicians for emotion recognition with auditory stimuli (e.g., Good et al., 2017; Lima & Castro, 2011; Thompson et al., 2004), and indicated that the association is domain-specific, because it did not extend to the visual domain. Moreover, musical ability, measured objectively, also predicted emotion recognition independently of music training and cognitive ability. In fact, untrained individuals with good musical abilities recognized vocal emotions with the same proficiency as trained musicians, and individual differences in music-perception skills mediated fully the association between music training and the ability to recognize vocal emotions.

The second study assessed the feasibility of conducting online experiments with measures of musical ability. To this end, we adapted the Musical Ear Test (MET; Wallentin et al., 2010) for online administration. The internal reliability of the online version proved to be similar to that of the original in-person testing format, and performance on the Melody and Rhythm subtests was correlated similarly. Positive associations with multiple facets of musical expertise validated the construct validity of the online test. As with the original format, music training was more closely associated with performance on the Melody than the Rhythm subtest, whereas Rhythm performance had stronger links with non-musical individual differences such as cognitive abilities. Overall, the findings and the large sample confirmed that it is possible and often advantageous to evaluate musical abilities online.

The third study explored individual differences among professional musicians, other musically trained individuals, and untrained individuals in terms of their musical skills, personality traits, and cognitive abilities. Compared to the untrained participants, both the musically trained and professional groups exhibited higher scores on several measures of musical ability, along with higher levels of openness, agreeableness and the personality metatrait stability. Professional musicians also had particularly high scores on measures of musical ability, extraversion, and the metatrait engagement. Surprisingly, although the musically trained group outperformed the untrained group on our cognitive-ability test, as expected (reviewed in Swaminathan & Schellenberg, 2019), professional musicians did not demonstrate better cognitive abilities compared to other participants. In fact, their performance was similar to that of untrained participants and worse than that of the musically trained group.

In the fourth study, the focus was on musically untrained individuals, particularly on how they vary regarding musical abilities and which variables predict their musicality. Interestingly, not only did untrained individuals vary widely in terms of musical abilities, but some of them exhibited superior musical abilities compared to the average musically trained individual. The results also indicated that, in the absence of training, individual differences in musical abilities are predicted by cognitive abilities and informal musical experiences, particularly untutored musical practice. This study highlighted that variables commonly linked to music training (except for the personality trait openness) also explain musical ability among individuals with no music lessons.

The final study investigated whether individuals have accurate self-awareness of their musical ability, and if such self-awareness correlates with other individual traits. On average, participants rated themselves higher in musical ability compared to their family and colleagues but similar compared to their friends and the general public. Evidence for accuracy of self-awareness came from positive correlations with a measure of musical sophistication, and with performance on an objective test of melody perception. Overestimates of musical ability tended to be more common among men compared to women, and among individuals with lower cognitive abilities. Self-estimates of musicality did not relate to age, education, or general cognitive ability, but they were positively linked to two personality traits: openness and extraversion.

7.2. Correlates of Musicality

As noted, musicality is a multifaceted concept that encompasses a range of attributes and skills related to the understanding, creation, and appreciation of music. The correlates of musicality can be explored in multiple ways by considering cognitive, emotional, social, and developmental variables. The present thesis focused on variables such as the ability to recognize emotions expressed vocally, self-reported musical behaviors (e.g., informal music learning and practice, active engagement with music), general cognitive abilities, personality, and self-awareness of musical abilities.

Although numerous studies have provided evidence for associations between music training and cognitive skills, such as language, executive functions, and working memory (e.g., for a review, see Swaminathan & Schellenberg, 2019), few provided evidence for associations with socioemotional abilities, particularly the ability to recognize emotions, a crucial socioemotional skill throughout life (e.g., Farmer et al., 2020; Lima & Castro, 2011; for a review, see Martins et al., 2021). Earlier findings were mixed regarding whether musicians had an edge in recognizing emotional cues in speech. Indeed, some studies failed to replicate the advantage for musicians (e.g., Park et al., 2015; Trimmer & Cuddy, 2008). In Chapter 2, we confirmed the hypothesized link between music training and the ability to recognize emotions conveyed through the voice but not through facial expressions, which suggests that the association is auditory-specific (as in Farmer et al., 2020). Nevertheless, this association was relatively small and, for speech prosody, it disappeared after controlling for digit span, which suggests that the association might be an artifact of general auditory abilities rather than a consequence of music training. By contrast, the association between musical abilities and recognizing vocal emotions remained strong even after accounting for individual differences in general cognitive abilities and music training. This result is consistent with studies that reported a positive association between musical abilities and other socioemotional skills, such as emotional regulation (e.g., Chin et al., 2013) and social interactions (e.g., Loeb et al., 2021).

Perhaps the most important finding was that untrained individuals with enhanced musical abilities were similar to highly trained musicians in their ability to recognize vocal emotions, indicating that the link between musicality and emotion recognition is better explained by music-perception abilities than by music training. A recent meta-analysis concluded that prosody perception is more strongly associated with music perception than with music training (Jansen et al., 2023), which corroborates our results. Moreover, Greenspon and Montanaro (2023) examined the same association using a music production (instead of perception) task, to evaluate singing ability, and found that music-production ability uniquely predicted emotion-recognition ability even after accounting for pitch-discrimination ability and musical experience. Earlier findings also documented that musical abilities were better than music training in explaining associations with nonverbal intelligence (Swaminathan et al., 2017) and language ability (Swaminathan & Schellenberg, 2020). Considered as a whole, the available evidence suggests that consideration of musical abilities is essential for a complete understanding of associations between music training and nonmusical skills, particularly the ability to recognize emotions from the human voice.

Despite this evidence, studies on the correlates of musicality tend to compare individuals with and without formal training in music, assuming that the acquisition and development of musical abilities is a consequence of formal music training (e.g., Bermudez & Zatorre, 2005; Obergfell et al., 2020; Park et al., 2015). Our results indicate, however, that musical abilities are strongly associated with informal musical activities that do not require music classes, such as singing, informal instrumental practice, and engaging actively with music (Chapter 3), and singing (Chapter 3). In other words, music training is just one of many correlates of musicality (e.g., Bigand & Poulin-Charronnat, 2006; Müllensiefen et al., 2014; Lima et al., 2020), such that untrained participants can exhibit the same advantages as musicians even though they never took music lessons.

In Chapter 5, we examined sociodemographic variables (age, gender, education), general cognitive ability, and personality, all of which are likely to play a role in gene-environment interactions (Gingras et al., 2015, 2018) and, therefore, influence the level of engagement with musical activities and the development of musical abilities. We first showed that musical abilities were positively associated with age and education, but not with gender. In other words, older and more educated individuals tend to have higher levels of musical abilities, a finding that extends prior results showing that music training is linked to socioeconomic status, with education being a key factor (e.g., Swaminathan et al., 2017; Swaminathan & Schellenberg, 2018). For gender, the null finding was consistent with others (e.g., Swaminathan et al., 2021; Wallentin et al., 2010), confirming that males and females are similar in terms of musical skills.

We measured general cognitive ability with a test of nonverbal abstract reasoning (MaRs-IB; Chierchia et al., 2019) in all studies except the first one, when we administered Digit Span (WAIS-III; Wechsler, 2008) instead. Across studies, but especially in Chapter 4, we found minimal evidence linking cognitive skills to music training, which contrasts with much of the literature that reported a positive link between music training and cognitive ability, especially in children (e.g., Moreno et al., 2011; Schellenberg, 2004, 2006; Silvia et al., 2016). In any event, as with the ability to recognize emotions from vocal cues, general cognitive ability was strongly associated with music-perception abilities, particularly with rhythm discrimination. Researchers have suggested that rhythm abilities are more hard-wired and universal than melody abilities, such that the development of rhythm is less dependent on formal training (e.g., Hansen et al., 2012; Swaminathan et al., 2021; Wallentin et al., 2010).

It remains to be explained why our results did not corroborate the association between music training and cognitive abilities in adults. A null finding was particularly provocative in Chapter 4, when musically trained nonprofessionals showed enhanced cognitive ability compared to professional musicians, despite having a shorter duration of training. Particularly during childhood and adolescence, individuals with enhanced cognitive abilities may be more inclined to take music lessons for extended periods of time, whereas individuals with lower levels of cognitive abilities may be more likely to discontinue or avoid training (Corrigall et al., 2013; Kragness et al., 2021; Müllensiefen et al., 2022). By early adulthood, most high-functioning individuals may opt for non-musical professions due to personal, practical, or skill-related reasons, which explains why professional musicians did not score particularly high on our test of cognitive ability. In principle, the cultural context (Portugal vs North America) could moderate the association, but we know of no evidence that would support this conjecture.

For personality, musically trained individuals exhibited higher levels of openness-to-experience (*openness*) and agreeableness compared to their untrained counterparts, as shown in Chapter 4. Moreover, among untrained individuals, openness predicted untutored musical practice, as described in Chapter 5. Although openness is often linked to music training (e.g., Butkovic et al., 2015; Corrigall et al., 2013; Gjermunds et al., 2020; Kuckelkorn et al., 2021; Vaag et al., 2018), the association between openness and musical practice extends this finding by showing that individuals with higher levels of openness are more likely to engage actively in playing music, independently of music training. It is somewhat surprising, therefore, that openness was *not* associated with musical ability as measured by objective tests (Chapter 5). Perhaps openness is a selective predictor of learning and playing music, irrespective of musical ability.

In Chapter 6, we found that self-reports of musicality were positively related to several musical behaviors and abilities, including the five dimensions of musical sophistication proposed by Müllensiefen et al. (2014; i.e., active engagement with music, self-reported music perception abilities, history of music lessons and practice, self-reported singing abilities, and emotional responses to music). In other words, our participants' notions of *musicality* were broad. Correlations with self-ratings were stronger, however, for music training, perceptual abilities, and singing abilities compared to emotional responses to music, which suggests that people intuitively associate musicality with the capacity to interpret and play music, which varies markedly across individuals, rather than with responding emotionally to music, which almost everyone does. Perhaps more important was the finding that individuals' musicality self-ratings were associated with an objective measure of music-perception abilities, specifically the same-different subtest of melody discrimination from the MET, but not with the rhythm subtest. This pattern—stronger associations for self-ratings with melody than with rhythm—mirror those reported previously for music training (Swaminathan et al., 2021). Self-reports of musicality were also correlated positively with the personality traits openness and extraversion, which are associated similarly with music training, but independent of general cognitive ability. Because self-awareness of musical abilities is examined rarely in the literature, future research is necessary to confirm our findings and improve our understanding of metacognitive abilities and their role in musical development.

In sum, performance on objective tests of musicality was associated with the ability to recognize vocal emotions, self-reported musical experiences, enhanced cognitive ability, and self-reports of musical abilities. More generally, except for the personality trait openness, variables linked commonly to music training were also related to musical ability.

7.3. Theoretical Implications

Identifying the theoretical implications of the results is crucial for advancing our knowledge of musical development and expertise. In this section, I consider (1) the conceptualization of musically trained and untrained groups of participants, (2) the nature vs. nurture debate in music research, and (3) the possibility of transfer effects from music training.

7.3.1. Musically Trained vs. Untrained Individuals

One key aspect of music research involves the conceptualization of groups of participants that are used to study cognition and behavior in relation to music. Individuals are often categorized as *musicians* or *nonmusicians* based on how long they took music lessons (e.g., Battcock & Schutz, 2021; Bermudez & Zatorre, 2005; Clayton et al., 2016). Grouping participants in this manner, with the intention of studying possible effects of music training, ignores the likely possibility that pre-existing individual differences determine who takes music lessons, as well as performance on a variety of behavioral measures. In the present thesis, we also formed groups of participants based on duration of music training. When naturally varying musical ability was the specific focus, music training was held constant either by statistical means (i.e., treating training as a covariate) or by restricting the sample to individuals with no training.

The findings from Chapter 4 highlighted significant differences among professional musicians and individuals with or without music training. On average, professionals had heightened levels of motivation to engage in musical activities (Appelgren et al., 2019), and particularly good musical abilities, a finding that was expected considering their long periods of practice (Bonde et al., 2018; Krampe & Ericsson, 1996). In terms of personality, professional musicians and musically trained nonprofessionals had higher levels of openness compared to untrained individuals. Professional musicians were distinguished, however, by their particularly high levels of the trait extraversion and the metatrait engagement, which is a combination of extraversion and openness. Although high levels of openness are often evident among musically trained individuals (e.g., Butkovic et al., 2015; Gjermunds et al., 2020; Kuckelkorn et al., 2021; Vaag et al., 2018), they are not predictive of opting to pursue a music career. Extraversion, by contrast, is more directly related to the social component of being a musician, such as teaching music, performing in public, and playing instruments in orchestras or bands. Previous research has linked engagement and extraversion with a variety of creative behaviors, including music (Feist, 2019; Sylvia, 2009).

In one instance (de Manzano & Úllen, 2021), however, professional musicians differed from other individuals in terms of openness, while amateur musicians differed from untrained individuals in terms of extraversion. Perhaps this discrepancy with the present findings stems from the fact that de Manzano and Úllen distinguished amateurs from professionals based on responses to a questionnaire about creative achievement, such that some of their amateurs would have been categorized as professionals in Chapter 4. The findings also differ from those of Kuckelkorn et al. (2021), who found higher levels of extraversion among a specific subgroup of professional musicians, namely singers. In Chapter 4, group differences in extraversion and engagement were *not* dependent on instrument category, although some categories had few participants and the analyses may have been underpowered. In any event, the present findings indicate that higher levels of openness and the metatrait stability predict the decision to engage and persist in music classes, whereas higher levels of extraversion and the metatrait engagement predict who pursues a career in music.

In stark contrast with evidence that music training improves nonmusical cognitive skills (e.g., Moreno et al., 2011; Schellenberg, 2004; Silvia et al., 2016), professional musicians, who have the most musical experience, performed worse than nonprofessional but musically trained individuals on a measure of general cognitive ability. Although some musicians have advanced intellectual capacity, professional musicians as a group appear to differ from other individuals primarily in terms of musical ability and personality rather than cognitive ability. This pattern of results contradicts the notion that associations between music training and cognitive abilities can be explained solely by plasticity, which would predict enhanced cognitive ability among individuals with longer periods of training.

For individuals without any formal music lessons, marked variability was evident in terms of musical abilities, with some untrained participants (> 10%) surpassing the mean of musicians on the MET (Chapter 5). Untrained individuals with higher musical abilities also tended to have high levels of general cognitive abilities and to engage in informal music-related activities, although they were not distinguished by their personalities. In sum, individual differences in musical abilities, personality, and cognitive abilities among musically trained and untrained individuals highlight relevant intra-group variability that has been overlooked in the literature. This variability needs to be considered when interpreting results and designing future studies because it would influence decisions to engage and persist in music classes, to become actively involved with music, and ultimately to choose a music-related job. Moreover, the findings suggest that musicality needs to be re-conceptualized such that it considers musical abilities and informal musical experiences and behaviors in addition to music training.

7.3.2. Revisiting the Nature vs. Nurture Debate in Music Research

Whether musical abilities are primarily innate or acquired through environmental exposure and training is a debate that has long fascinated researchers from numerous disciplines. Traditionally, the importance of formal music training in developing musical expertise has been emphasized (e.g., Ericsson et al., 1993; Trainor & Corrigall, 2010), but the present findings confirm that some individuals with no lessons are nevertheless exceptional in terms of musical abilities. These individuals are also similar to trained musicians in terms of cognitive as well as musical ability (melody and rhythm processing), although they have higher levels of education and lower levels of the personality trait openness.

Two relevant conclusions can be drawn from our results. First, because good musical abilities are evident in some untrained individuals (Chapter 5), music training cannot be the only factor responsible for their emergence and development. Second, musically trained and untrained individuals display individual differences in terms of personality and education levels that are unlikely to be explained, in part or in full, by training (Chapters 4 and 5). These findings are consistent with evidence from twin studies indicating that genetic predispositions underly various facets of musical ability and achievement (e.g., Hambrick & Tucker-Drob, 2015; Tan et al., 2014). Genetic variations appear to influence an individual's musical potential, such that certain individuals excel in musical domains from an early age (Glasser & McPherson, 2023).

Our studies also highlighted that musicians' advantage in general cognitive ability or recognizing emotions in voices did not stem solely from music training (Chapters 2 and 4). Rather, natural predispositions and informal engagement with music needed to be considered (see also Schellenberg & Mankarious, 2012). Moreover, in Chapter 3, early music training was not associated with certain aspects of musical abilities, particularly rhythm discrimination, which belies proposals that early music training has a particularly strong impact on musical skills (e.g., Penhune, 2019, 2020; Svec, 2018; Trainor & Corrigall, 2010).

The present findings, particularly from Chapter 5, highlight a link between musical abilities and instrumental music practice that occurs independently of training, in line with previous studies of musical abilities that are independent of formal lessons (e.g., Bigand & Poulin-Charronnat, 2006; Müllensiefen et al., 2014). Even though predispositions lay the foundation for musical abilities, environmental factors are crucial for their expression and refinement—a gene-environment interplay (e.g., Gingras et al., 2015, 2018). Early exposure to music, supportive family environments, access to music education, cultural influences, and other environmental factors mediate the association between genetic predispositions and expert levels of musical performance (e.g., Corrigall & Schellenberg, 2015; Glasser & McPherson, 2023; Kreutz & Feldhaus, 2023; Theorell et al., 2015).

The obvious answer to questions of causation would be to conduct a randomized controlled experiment, with pre- and post-testing for individuals assigned to music training or to a control group that receives equally interesting but challenging nonmusical training. Nevertheless, by eliminating self-selection factors, it is impossible to understand the role of innate predispositions, which can influence who takes music lessons and moderate any effects they may have. On the one hand, the studies in this dissertation are cross-sectional and therefore preclude clear inferences of causation. On the other hand, they allow consideration of pre-existing factors that distinguish individuals with higher or lower musical abilities, and the personal decision to engage in music lessons. The findings provide unequivocal evidence that it is important to investigate the role of pre-existing individual differences in musical skills, cognitive abilities, personality, and demographics. More generally, a comprehensive understanding of the complex interplay between music training and its correlates requires consideration of influences from both nature and nurture.

7.3.3. Re-evaluating Transfer Effects in Music Training

Music training is often considered to be a good example of neuroplasticity, with intensive music training and practice inducing structural and functional changes in the brain, accompanied by changes in behavior that extend beyond musical domains (e.g., Herholz & Zatorre, 2012; Münte et al., 2002). Our results suggest that this view is misleading. First, although there was an association between music training and the ability to recognize emotions from voices (Chapter 2), this link was better explained by musical abilities than by training (see Jansen et al., 2023), a finding consistent with other investigations of variables traditionally linked to music training (e.g., second-language ability, Thompson et al., 2024; cognitive ability, Swaminathan & Schellenberg, 2018; emotional regulation, Chin et al., 2013). Second, although the musically trained group showed enhanced cognitive ability compared to the untrained group (Chapter 4), as expected (e.g., Swaminathan & Schellenberg, 2019), this advantage did not extend to professional musicians with the most years of training and practice, who, surprisingly, performed at the level of untrained individuals. Third, cognitive ability predicted musical abilities in the absence of formal training (Chapter 5), as it has in previous studies with children (e.g., Norton et al., 2005; Swaminathan & Schellenberg, 2018). In short, individuals with better musical abilities demonstrated better performance on nonmusical measures of general cognitive ability and recognition of vocal emotions, even after accounting for contributions from formal music training. These outcomes pose a challenge to theories proposing that learning music improves nonmusical cognitive abilities (e.g., Patel, 2011; Tierney & Kraus, 2013), and question the possibility of far transfer to cognitive and socioemotional domains as a result of plasticity caused by music training (e.g., Sala & Gobet, 2020; Degé, 2021).

Inconsistent results for transfer effects from music training to cognitive and socioemotional skills are also likely to stem from differences in pedagogical approaches, such as the emphasis attributed to different elements of musical expertise in music training. In Chapters 3 to 6, music training and instrumental practice were better at predicting performance on the melody- compared to the rhythm-discrimination subtest of the MET, which aligns with previous findings showing that duration of lessons has a stronger association with Melody than Rhythm (e.g., Ilari et al., 2016; Swaminathan et al., 2021). Because rhythm discrimination was more strongly correlated with general cognitive ability compared to melody discrimination, rhythm processing appears to be less dependent on experience, whereas melody processing is more adaptable to environmental influences and exposure to the music of one's culture. Even within a musical culture, however, different pedagogical approaches or choices of musical instrument could influence distinct elements of musical expertise differently. Moreover, even when the same instrument is learned with the same teaching method in the same context, the experience and its possible by-products would likely be influenced by the efficacy of the instructor and the relationship between instructor and student (e.g., Portowitz et al., 2009). Finally, whether music is taught individually or in groups is likely to be an important factor, particularly regarding affective state and interpersonal skills (e.g., Kokotsaki & Hallam, 2007; Stewart & Lonsdale, 2016). In short, if music training does indeed have reliable transfer effects, such effects are almost certain to vary as a function of differences between cultures, pedagogies, and instructors.

Overall, although traditional views emphasize the direct impact of music training on nonmusical abilities, our findings suggest that natural musical ability, rather than duration or intensity of training, is the critical factor driving the observed associations. Music training could then act as a catalyst for the development and refinement of specific perceptual abilities that underlie enhanced performance on both musical and nonmusical tasks. Nevertheless, the contribution of music training to objective musical ability appears limited, as is its contribution to general cognitive ability, which are both influenced primarily by innate predispositions rather than formal training (e.g., Tan et al., 2014). Understanding reciprocal associations between music training and musical abilities is essential for forming mechanistic explanations of how music training is related to performance in nonmusical tasks. In short, a complete understanding of the possibility of far-transfer effects from music training relies on a detailed understanding of near-transfer effects.

7.4. Practical Implications

By shedding light on several facets of musicality and its associations with cognitive abilities, personality traits, and sociodemographic factors, the present results challenge the conventional notion that music training is responsible for the development of musical abilities and individual differences in nonmusical abilities. The findings also highlight the importance of distinguishing between different dimensions of musicality and their respective associations with cognitive skills. Although general cognitive abilities showed minimal associations with music training (Chapters 4 and 5), they exhibited stronger correlations with music-perception abilities, particularly rhythm discrimination, which appears to be less dependent on training than melody discrimination.

Implications for educational practices and policies include rethinking the idea that music training is a panacea for improving cognitive and socioemotional abilities across multiple domains. Although educators and policymakers could prioritize the development of certain musical skills that appear to be better predictors of performance on nonmusical tasks, such an approach devalues music for its own sake. The present results underscore the need for a comprehensive approach to music education, which considers different elements that interact to explain the observed effects, such as innate predispositions for musicality, different musical elements emphasized during training, cultural influences, and the socioemotional benefits of engaging in musical activities. Listening to music or practicing a musical instrument, in particular, has been associated with high levels of enjoyment while performing those activities, and with the ability to express and regulate emotions (e.g., Gurgen, 2016; Thoma et al., 2012). Instead of emphasizing primarily the potential cognitive benefits of music training, music educators could prioritize musical experiences that are comprehensive, involving musical appreciation, creativity, and emotional expression.

Importantly, the emotional benefits of music are universal and independent of formal music lessons. Given the link between musical abilities and socioemotional abilities regardless of training (Chapter 2), psychotherapists could consider improving musical ability as a means of promoting emotional development and reducing symptoms in psychiatric disorders, such as depression and anxiety. Moreover, the universality of associations between musical abilities and nonmusical outcomes points to the relevance of promoting a rich musical environment that nurtures the development of musical abilities throughout the lifespan.

In short, while cognitive effects of music training are often stressed in the literature, the low likelihood of transfer effects highlights the importance of promoting music for its intrinsic value, enjoyment, and potential socioemotional benefits.

7.5. Limitations and Recommendations

Although this thesis provided relevant insights into the correlates of musical abilities, limitations in the design and implementation of the studies may have impacted the interpretation and generalizability of our findings. For example, we used only one measure of general cognitive ability in each study, namely a test of auditory working memory in the first study, and a task of nonverbal abstract reasoning in the remaining studies. Thus, our ability to draw broad conclusions about general cognitive abilities is limited. Even though measures of abstract reasoning and working memory tend to be suitable stand-alone proxies for general intelligence when it is unfeasible to administer a comprehensive battery of tests (e.g., Deary & Smith, 2004), it remains important to replicate these studies considering a wider range of cognitive skills.

Due to the constraints of online experiments in studies two to five, only music perception skills were evaluated as measures of musical ability, particularly melody and rhythm discrimination. Although this is a common practice in music research (e.g., Hansen et al., 2012; Swaminathan et al., 2017; Talamini et al., 2023), it would be interesting to include a more comprehensive set of musical tasks, particularly tests of music production (e.g., beat alignment, melody copy), and tests of musical skills other than melody and rhythm. Examining how different musical skills influence the development of musical and nonmusical abilities will improve our understanding of whether music training can improve those skills, and help to identify which elements of music training are associated specifically with certain outcomes.

Our findings also highlight significant disparities between professional musicians and other musically trained individuals. Future studies could confirm and explore the observed associations in more depth, considering, for example, distinctions regarding the instruments played by the musicians, which might be associated with innate factors, such as specific personality traits (e.g., Kuckelkorn et al., 2021). Among individuals with no music lessons, we showed that individual differences in musical ability, personality, and cognition, alongside contextual factors like socio-economic status, collectively shape developmental paths in musical experience. Future studies could aim to replicate and extend these results using developmental, longitudinal, and correlational approaches. All in all, individual differences within groups must be carefully considered when interpreting published research and designing future studies.

7.6. Concluding Remarks

In this thesis, we explored the multifaceted nature of musical abilities and their correlates among musically trained and untrained individuals. Through a series of five studies, we examined distinctions between professional musicians, other musically trained individuals, and musically untrained individuals, shedding light on numerous factors that influence their musicality.

Our findings challenge traditional perceptions of musical abilities as the mere product of formal music training. While formal training contributes to improved music-performance skills, we demonstrated that predispositions and informal engagement with music also play a significant role in explaining individual differences in musical aptitude. Moreover, contrary to traditional perspectives, our studies provided very limited evidence for transfer effects from music training to nonmusical cognitive and socioemotional abilities. Instead, they suggested that proficiency in musical abilities, rather than the duration or intensity of music training, explains any associations.

The present studies highlighted the relevance of considering the musicality of untrained individuals, as well as differences among musically trained individuals, to reach a comprehensive understanding of associations between music training and nonmusical abilities. The results also had practical implications for music education and cognitive development. Rather than considering music training as an enhancer of multiple cognitive and socioemotional skills, music educators could instead emphasize the inherent value of music, or prioritize the development of specific musical abilities that are most closely associated with enhanced performance on musical and nonmusical tasks.

All things considered, the studies included in this thesis provide important knowledge about the role of musical abilities in associations between music training and nonmusical abilities. By proposing alternatives through which musical abilities can be acquired and developed, the findings inform the design of future research and educational initiatives that aim to foster musical engagement and proficiency in different populations.

References

Appelgren, A., Osika, W., Theorell, T., Madison, G., & Bojner Horwitz, E. (2019). Tuning in on motivation: Differences between non-musicians, amateurs, and professional musicians. *Psychology of Music*, *47*(6), 864–873. https://doi.org/10.1177/0305735619861435

Battcock, A., & Schutz, M. (2021). Emotion and expertise: How listeners with formal music training use cues to perceive emotion. *Psychological Research*, *86*(1), 66–86. https://doi.org/10.1007/s00426-020-01467-1

Bermudez, P., & Zatorre, R. J. (2005). Differences in gray matter between musicians and nonmusicians. *Annals of the New York Academy of Sciences*, *1060*(1), 395–399. https://doi.org/10.1196/annals.1360.057

Bigand, E., & Poulin-Charronnat, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition*, *100*(1), 100–130. https://doi.org/10.1016/j.cognition.2005.11.007

Bonde, L. O., Juel, K., & Ekholm, O. (2018). Associations between music and health-related outcomes in adult non-musicians, amateur musicians and professional musicians—Results from a nationwide Danish study. *Nordic Journal of Music Therapy*, 27(4), 262–282. https://doi.org/10.1080/08098131.2018.1439086

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of musical practice: Underlying environmental and genetic influences. *Personality and Individual Differences, 74*, 133–138. https://doi.org/10.1016/j.paid.2014.10.006

Chierchia, G., Fuhrmann, D., Knoll, L. J., Pi-Sunyer, B. P., Sakhardande, A. L., & Blakemore, S. (2019). The matrix reasoning item bank (MaRs-IB): Novel, open-access abstract reasoning items for adolescents and adults. *Royal Society Open Science*, *6*(10), Article 190232. https://doi.org/10.1098/rsos.190232

Chin, T., & Rickard, N. S. (2013). Emotion regulation strategy mediates both positive and negative relationships between music uses and well-being. *Psychology of Music*, *42*(5), 692–713. https://doi.org/10.1177/0305735613489916

Clayton, K. K., Swaminathan, J., Yazdanbakhsh, A., Zuk, J., Patel, A. D., & Kidd, G. (2016). Executive function, visual attention and the cocktail party problem in musicians and Non-Musicians. *PLoS ONE*, *11*(7). https://doi.org/10.1371/journal.pone.0157638

Corrigall, K. A., & Schellenberg, E. G. (2015). Predicting who takes music lessons: Parent and child characteristics. *Frontiers in Psychology*, *6*, Article 282. https://doi.org/10.3389/fpsyg.2015.00282

Corrigall, K. A., Schellenberg, E. G., & Misura, N. A. (2013). Music training, cognition, and personality. *Frontiers in Psychology*, *4*, Article 222. https://doi.org/10.3389/fpsyg.2013.00222

Deary, I. J., & Smith, P. (2004). Intelligence research and assessment in the United Kingdom. In R. J. Sternberg (Ed.), *International handbook of intelligence* (pp. 1–48). Cambridge University Press. https://doi.org/10.1017/CBO9780511616648.002

Degé, F. (2021). Music lessons and cognitive abilities in children: How far transfer could be possible. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.557807

Ericsson, K. A., Krampe, R. T., and Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363–406. https://doi.org/10.1037/0033-295X.87.3.215

Farmer, E., Jicol, C., & Petrini, K. (2020). Musicianship enhances perception but not feeling of emotion from others' social interaction through speech prosody. *Music Perception*, *37*(4), 323–338. https://doi.org/10.1525/mp.2020.37.4.323

Gingras, B., Honing, H., Peretz, I., Trainor, L. J., & Fisher, S. E. (2015). Defining the biological bases of individual differences in musicality. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1664), 20140092. https://doi.org/10.1098/rstb.2014.0092

Gingras, B., Honing, H., Peretz, I., Trainor, L. J., & Fisher, S. E. (2018). Defining the biological bases of individual differences in musicality. In H. Honing (Ed.), *The Origins of Musicality* (pp. 221–250). MIT Press. https://doi.org/10.7551/mitpress/10636.003.0015

Glasser, S., & McPherson, G. E. (2023). The role of natural abilities in early childhood musical development. In M. S. Barrett, & G. F. Welch (Eds.), *The Oxford Handbook of Early Childhood Learning and Development in Music* (pp. 801–821). Oxford University Press

Gjermunds, N., Brechan, I., Johnsen, S., & Watten, R. G. (2020). Personality traits in musicians. *Current Issues in Personality Psychology*, *8*(2), 100–107. https://doi.org/10.5114/cipp.2020.97314

Good, A., Gordon, K. A., Papsin, B. C., Nespoli, G., Hopyan, T., Peretz, I., & Russo, F. A. (2017). Benefits of music training for perception of emotional speech prosody in deaf children with cochlear implants. *Ear And Hearing*, *38*(4), 455-464. https://doi.org/10.1097/aud.0000000000000402

Greenspon, E. B., & Montanaro, V. (2023). Singing ability is related to vocal emotion recognition: Evidence for shared sensorimotor processing across speech and Music. *Attention, Perception, & Psychophysics*, *85*(1), 234–243. https://doi.org/10.3758/s13414-022-02613-0

Gurgen, E. (2016). Social and emotional function of musical listening: Reasons for listening to music. *Eurasian Journal of Educational Research*, *16*(66), 1–30. https://doi.org/10.14689/ejer.2016.66.13

Hambrick, D. Z., & Tucker-Drob, E. M. (2015). The genetics of music accomplishment: Evidence for gene–environment correlation and interaction. *Psychonomic Bulletin & Review, 22*(1), 112–120. https:// doi.org/10.3758/s13423-014-0671-9

Hansen, M., Wallentin, M., & Vuust, P. (2012). Working memory and musical competence of musicians and non-musicians. *Psychology of Music, 41*(6), 779-793. https://doi.org/10.1177/0305735612452186

Herholz, S. C., & Zatorre, R. J. (2012). Musical training as a framework for brain plasticity: Behavior, function, and structure. *Neuron*, *76*(3), 486-502. https://doi.org/10.1016/j.neuron.2012.10.011

Ilari, B. S., Keller, P., Damasio, H., & Habibi, A. (2016). The development of musical skills of underprivileged children over the course of 1 year: A study in the context of an El Sistema-inspired program. *Frontiers in Psychology, 7*:62. https://doi.org/10.3389/fpsyg.2016.00062

Jansen, N., Harding, E. E., Loerts, H., Başkent, D., & Lowie, W. (2023). The relation between musical abilities and speech prosody perception: A meta-analysis. *Journal of Phonetics*, *101*, 101278. https://doi.org/10.1016/j.wocn.2023.101278

Kokotsaki, D., & Hallam, S. (2007). Higher Education Music Students' perceptions of the benefits of participative music making. *Music Education Research*, *9*(1), 93–109. https://doi.org/10.1080/14613800601127577

Kragness, H. E., Swaminathan, S., Cirelli, L. K., & Schellenberg, E. G. (2021). Individual differences in musical ability are stable over time in childhood. *Developmental Science*. Advance online publication. https://doi.org/10.1111/desc.13081

Krampe, R. T., & Ericsson, K. A. (1996). Maintaining excellence: Deliberate practice and elite performance in young and older pianists. *Journal of Experimental Psychology: General, 125*(4), 331–359. https://doi.org/10.1037/0096-3445.125.4.331

Kreutz, G., & Feldhaus, M. (2023). The influence of parent–child relationships on musical activity in the family: Findings from a longitudinal panel study. *Music & Science*, *6*, 205920432211493. https://doi.org/10.1177/20592043221149351

Kuckelkorn, K., de Manzano, Ö., & Ullén, F. (2021). Musical expertise and personality—differences related to occupational choice and instrument categories. *Personality and Individual Differences*, *173*, Article 110573. https://doi.org/10.1016/j.paid.2020.110573

Lima, C. F., & Castro, S. L. (2011). Speaking to the trained ear: Musical expertise enhances the recognition of emotional speech prosody. *Emotion, 11*(5), 1021-1031. https://doi.org/10.1037/a0024521

Lima, C. F., Correia, A. I., Müllensiefen, D., & Castro, S. L. (2020). Goldsmiths Musical Sophistication Index (Gold-MSI): Portuguese version and associations with socio-demographic factors, personality and music preferences. *Psychology of Music*, *48*(3), 376–388. https://doi.org/10.1177/0305735618801997

Loeb, D., Reed, J., Golinkoff, R. M., & Hirsh-Pasek, K. (2021). Tuned in: Musical rhythm and social skills in adults. *Psychology of Music*, *49*(2), 273–286. https://doi.org/10.1177/0305735619850880

Martins, M., Pinheiro, A. P., & Lima, C. F. (2021). Does music training improve emotion recognition abilities? A critical review. *Emotion Review, 13*(3), 199-210. https://doi.org/10.1177/17540739211022035

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425–1433. https://doi.org/10.1177/0956797611416999

Müllensiefen, D., Elvers, P., & Frieler, K. (2022). Musical development during adolescence: Perceptual Skills, cognitive resources, and musical training. *Annals of the New York Academy of Sciences*, *1518*(1), 264–281. https://doi.org/10.1111/nyas.14911

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS ONE*, *9*(2), Article e89642. https://doi.org/10.1371/journal.pone.0089642

Münte, T. F., Altenmüller, E., & Jäncke, L. (2002). The musician's brain as a model of neuroplasticity. *Nature Reviews Neuroscience*, *3*(6), 473–478. https://doi.org/10.1038/nrn843

Norton, A., Winner, E., Cronin, K., Overy, K., Lee, D. J., & Schlaug, G. (2005). Are there pre-existing neural, cognitive, or motoric markers for musical ability? *Brain and Cognition*, *59*(2), 124–134. https://doi.org/10.1016/j.bandc.2005.05.009

Obergfell, A. L., Schmidt, B. M., Stenneken, P., Wittemann, S. K., & Schabmann, A. (2020). Prosodic sensitivity and reading fluency of musicians and non-musicians. *Reading and Writing*, *34*(4), 887–909. https://doi.org/10.1007/s11145-020-10096-4

Park, M., Gutyrchik, E., Welker, L., Carl, P., Poppel, E., Zaytseva, Y., Meindl, T., Blautzik, J., Reiser, M., & Bao, Y. (2015). Sadness is unique: neural processing of emotions in speech prosody in musicians and nonmusicians. *Frontiers in Human Neuroscience, 8,* 1-8. https://doi.org/10.3389/fnhum.2014.01049

Patel, A. D. (2011). Why would musical training benefit the neural encoding of speech? The OPERA hypothesis, *8. Frontiers in Psychology, 2*. https://doi.org/10.3389/fpsyg.2011.00142

Penhune, V. B. (2019). Musical expertise and brain structure: The causes and consequences of training. In M. H. Thaut & D. A. Hedges, (Eds.), *The Oxford handbook of music and the brain* (pp. 417–438). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198804123.013.17

Penhune, V. B. (2020). A gene-maturation-environment model for understanding sensitive period effects in musical training. *Current Opinion in Behavioral Sciences*, *36*, 13–22. https://doi.org/10.1016/j.cobeha.2020.05.011

Portowitz, A., Lichtenstein, O., Egorova, L., & Brand, E. (2009). Underlying mechanisms linking music education and cognitive modifiability. *Research Studies in Music Education*, *31*(2), 107–128. https://doi.org/10.1177/1321103x09344378

Sala, G., & Gobet, F. (2020). Cognitive and academic benefits of music training with children: A multilevel meta-analysis. *Memory & Cognition, 48*(8), 1429–1441. https://doi.org/10.3758/s13421-020-01060-2

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology*, *98*(2), 457–468. https://doi.org/10.1037/0022-0663.98.2.457

Schellenberg, E. G. (2004). Music lessons enhance IQ. *Psychological Science*, *15*(8), 511–514. https://doi.org/10.1111/j.0956-7976.2004.00711.x

Schellenberg, E. G., & Mankarious, M. (2012). Music training and emotion comprehension in childhood. *Emotion, 12*(5), 887–891. https://doi.org/10.1037/a0027971

Silvia, P. J., Thomas, K. S., Nusbaum, E. C., Beaty, R. E., & Hodges, D. A. (2016). How does music training predict cognitive abilities? A bifactor approach to musical expertise and intelligence. *Psychology of Aesthetics, Creativity, and the Arts*, *10*(2), 184–190. https://doi.org/10.1037/aca0000058

Stewart, N. A., & Lonsdale, A. J. (2016). It's Better together: The psychological benefits of singing in a choir. *Psychology of Music*, *44*(6), 1240–1254. https://doi.org/10.1177/0305735615624976

Svec, C. L. (2018). The effects of instruction on the singing ability of children ages 5 to 11: A meta-analysis. *Psychology of Music*, *46*(3), 326–339. https://doi.org/10.1177/0305735617709920

Swaminathan, S., Kragness, H. E., & Schellenberg, E. G. (2021). The Musical Ear Test: Norms and correlates from a large sample of Canadian undergraduates. *Behavior Research Methods*. Advance online publication. https://doi.org/10.3758/s13428-020-01528-8

Swaminathan, S., & Schellenberg, E. G. (2018). Musical competence is predicted by music training, cognitive abilities, and personality. *Scientific Reports*, *8*(1), Article 9223. https://doi.org/10.1038/s41598-018-27571-2

Swaminathan, S., & Schellenberg, E. G. (2019). Music training and cognitive abilities: Associations, causes, and consequences. In M. H. Thaut & D. A. Hodges (Eds.), *The Oxford handbook of music and the brain* (pp. 645–670). Oxford University Press. http://dx.doi.org/10.1093/oxfordhb/9780198804123.013.26

Swaminathan, S., & Schellenberg, E. G. (2020). Musical ability, music training, and language ability in childhood. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *46*(12), 2340–2348. https://doi.org/10.1037/xlm0000798

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude? *Intelligence*, *62*, 119–124. https://doi.org/10.1016/j.intell.2017.03.005

Talamini, F., Vigl, J., Doerr, E., Grassi, M., & Carretti, B. (2022). Auditory and visual mental imagery in musicians and non-musicians. *Musicae Scientiae*, *27*(2), 428–441. https://doi.org/10.1177/10298649211062724

Tan, Y. T., McPherson, G. E., Peretz, I., Berkovic, S. F., & Wilson, S. J. (2014). The genetic basis of music ability. *Frontiers in Psychology,* *5*:658. https://doi.org/10.3389/fpsyg.2014.00658

Theorell, T., Lennartsson, A. K., Madison, G., Mosing, M. A., & Ullén, F. (2015). Predictors of continued playing or singing – from childhood and adolescence to adult years. *Acta Paediatrica*, *104*(3), 274–284. https://doi.org/10.1111/apa.12870

Thoma, M. V., Ryf, S., Mohiyeddini, C., Ehlert, U., & Nater, U. M. (2012). Emotion regulation through listening to music in everyday situations. *Cognition & Emotion*, *26*(3), 550–560. https://doi.org/10.1080/02699931.2011.595390

Thompson, W. F., & Salig, L. K. (2024). Is musical ability related to second-language acquisition? A meta-analysis. [Manuscript submitted for publication]. University of Maryland College Park, University of Maryland.

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2004). Decoding speech prosody: Do music lessons help?. *Emotion*, *4*(1), 46-64. https://doi.org/10.1037/1528-3542.4.1.46

Tierney, A., & Kraus, N. (2013). Music training for the development of reading skills. *Progress in Brain Research, 207*, 209–241. https://doi.org/10.1016/B978-0-444-63327-9.00008-4

Trainor, L. J., & Corrigall, K. A. (2010). Music acquisition and effects of musical experience. In M. R. Jones, R. R. Fay, & A. N. Popper (Eds.), *Music perception* (pp. 89–127). Springer Science + Business Media. https://doi.org/10.1007/978-1-4419-6114-3_4

Trimmer, C. G., & Cuddy, L. L. (2008). Emotional intelligence, not music training, predicts recognition of emotional speech prosody. *Emotion, 8*(6), 838-849. https://doi.org/10.1037/a0014080

Vaag, J., Sund, E. R., & Bjerkeset, O. (2018). Five-factor personality profiles among Norwegian musicians compared to the General Workforce. *Musicae Scientiae*, *22*(3), 434–445. https://doi.org/10.1177/1029864917709519

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010). The Musical Ear Test, a new reliable test for measuring musical competence. *Learning and Individual Differences*, *20*(3), 188–196. https://doi.org/10.1016/j.lindif.2010.02.004

Wechsler, D. (2008). *WAIS-III: Manual da Escala de Inteligência de Wechsler para Adultos – 3ª Edição.* Lisboa: CEGOC-TEA.

APPENDICES

APPENDIX A

Supplementary Materials for Study 2 (Chapter 3)

Supplementary Table 3.1 provides Cronbach's alphas for Gold-MSI scores. Supplementary Table 3.2 provides Cronbach's alphas for the Big Five Inventory (BFI) and the Mind Wandering Questionnaire (MWQ).

Demographic Variables

We examined whether the present sample differed from comparison samples (Lima et al., 2020; Swaminathan et al., 2021) in terms of gender, age, years of education, and duration of music training. Although women were the majority in all three samples, the proportion who were men was decisively higher in the present sample (40.2%) than in Lima et al. (25.0%), $c^2(1, N = 1012) = 25.14$, $p < .001$, $BF_{10} > 100$. It was also higher than in Swaminathan et al. (32.4%), $c^2(1, N = 1122) = 7.31$, $p = .007$, $BF_{10} = 2.99$, but the observed data provided only weak evidence for a group difference.

Mean age of participants did not differ between the present sample ($M = 34.22$, $SD = 15.11$) and that of Lima et al. ($M = 32.95$, $SD = 14.38$), $p = .181$, $BF_{10} = 0.17$, with substantial evidence favoring the null hypothesis. The present sample was considerably older than the undergraduates tested by Swaminathan et al. ($M = 19.04$, $SD = 2.03$), $t(632.36) = 24.52$, $p < .001$ (unequal variances test), and the variance was greater, $F(607, 522) = 892.49$, $p < .001$. The observed data provided decisive evidence for the group difference in age, $BF_{10} > 100$.

The sample of undergraduates from Swaminathan et al. (2021) varied minimally in terms of education. Compared to the sample from Lima et al. (2020, $M = 6.94$, $SD = 2.11$), the present sample had less education ($M = 6.16$, $SD = 1.05$), $t(552.19) = 6.84$, $p < .001$ (unequal variances test), Cohen's $d = .490$, $BF_{10} > 100$, and less variance in terms of age, $F(565, 407) = 326.67$, $p < .001$.

Participants in the present sample had more music training ($M = 4.26$, $SD = 2.30$) than those in the sample from Lima et al. ($M = 2.68$, $SD = 1.93$), $t(966.32) = 11.84$, $p < .001$ (unequal variances test), Cohen's $d = .744$, $BF_{10} > 100$, and more variability in training, $F(607, 407) = 20.98$, $p < .001$. Because Swaminathan et al. (2021) treated duration of music training as a continuous variable, we re-coded the variable so that it conformed to item 36 from the Gold-

MSI (ordinal scale), thereby making duration of training comparable across samples. The present sample had more music training than participants tested by Swaminathan et al. (*M* = 3.78, *SD* = 2.40), $t(1089.60) = 3.42$, $p < .001$ (unequal variances test), Cohen's $d = .204$, $BF_{10} = 21.4$, although variance was greater in the previous sample, $F(607, 522) = 7.10$, $p = .008$.

Personality

Swaminathan et al. (2021) did not report personality data. Comparisons of the present sample with the sample tested by Lima et al. (2020) are provided in Supplementary Table 3.3. The present sample had higher levels of openness-to-experience and neuroticism, and lower levels on conscientiousness, extroversion, and agreeableness. The observed data provided decisive evidence for group differences in openness-to-experience and agreeableness, very strong evidence for differences in extroversion, and substantial evidence for differences in conscientiousness and neuroticism. Variance in agreeableness was also notably greater for the previous sample, $F(607, 394) = 7.75$, $p = .005$.

Correlations Between Predictor Variables and the Gold-MSI

Pairwise correlations among potential predictor variables are provided in Supplementary Table 3.4. Multiple associations were evident, many for which the observed data provided decisive evidence. Specifically, with increasing age, participants were more likely to be men, to have more education, and to score higher on openness-to-experience, conscientiousness, and extroversion. Older individuals also tended to have lower scores on our measures of cognitive ability, mind-wandering, and neuroticism. Analyses of gender revealed that women scored higher than men on two personality dimensions: agreeableness and neuroticism. Amount of education was correlated positively with cognitive ability and conscientiousness, but negatively with mind-wandering and neuroticism.

Cognitive ability had no additional associations with mind-wandering or personality. Mind-wandering was associated negatively, however, with conscientiousness, extroversion, and agreeableness, but positively with neuroticism. Associations among personality variables also revealed considerable overlap. Extroversion was correlated positively with openness-to-experience, conscientiousness, and agreeableness, but negatively with neuroticism; neuroticism had additional negative associations with conscientiousness and agreeableness; and conscientiousness was correlated positively with agreeableness.

Supplementary Table 3.5 provides pairwise correlations among the Gold-MSI subscales and the General Factor. The observed data provided decisive evidence that all pairs of variables were associated positively. Supplementary Table 3.6 provides correlations between Gold-MSI scores and other predictor variables. The main finding was that there was decisive evidence of a positive correlation between openness-to-experience and *all* Gold-MSI scores.

Supplementary Table 3.1

Reliability (Cronbach's alpha) and Descriptive Statistics for the Gold-MSI Subtests and the General Factor. Data are Presented for the Whole Sample and Separately for the Unpublished Italian and Brazilian Versions. For Comparison Purposes, Values from Lima et al. (2020) are Also Provided.

	Current Online Sample											
	Whole sample (*N* = 608)			Italian Gold-MSI (*n* = 288)			Brazilian Gold-MSI (*n* = 123)			Lima et al., 2020 (*N* = 408)		
Gold-MSI Subtest	α	*M*	*SD*	α	*M*	*SD*	α	*M*	*SD*	α	*M*	*SD*
Active Engagement	.85	4.36	1.21	.88	4.17	1.29	.83	4.58	1.20	.85	3.67	1.15
Perceptual Abilities	.87	5.53	1.07	.88	5.46	1.15	.86	5.67	1.04	.85	4.95	0.97
Music Training	.92	3.96	1.83	.93	3.92	1.96	.91	4.45	1.70	.89	2.64	1.45
Singing Abilities	.84	4.42	1.36	.87	4.34	1.48	.78	4.57	1.23	.83	3.81	1.21
Emotions	.69	5.75	0.86	.68	5.63	0.85	.74	5.83	0.96	.82	5.22	1.06
General Factor	.92	4.41	1.29	.94	4.27	1.42	.90	4.73	1.14	.91	3.60	1.07

Supplementary Table 3.2

Reliability Statistics (Cronbach's Alphas) for Scores on the Big Five Inventory (BFI) and the Mind Mind-Wandering Questionnaire (MWQ).

	Cronbach's Alpha				
	Whole Sample (*N* = 754)	Italian (*n* = 341)	European Portuguese (*n* = 185)	Brazilian Portuguese (*n* = 161)	English (*n* = 67)
BFI					
Extraversion	.84	.84	.86	.83	.83
Agreeableness	.69	.72	.69	.66	.76
Neuroticism	.85	.86	.88	.81	.85
Conscientiousness	.81	.85	.80	.69	.85
Openness	.80	.79	.82	.80	.76
MWQ	.85	.82	.84	.86	.84

Supplementary Table 3.3

Comparisons of Personality Data from the Big Five Inventory Between the Present Sample and Lima et al. (2020).

	Present Sample *N* = 608 Mean (*SD*)	Lima et al. (2020) *N* = 395 Mean (*SD*)	*p*	Cohen's *d*	BF_{10}
Openness	4.01 (.58)	3.57 (.66)	< .001	.721	> 100
Conscientiousness	3.58 (.70)	3.70 (.64)	.003	.190	4.92
Extroversion	3.19 (.79)	3.38 (.78)	< .001	.241	65.4
Agreeableness	3.79 (.54)	3.95 (.48)	< .001	.306	> 100
Neuroticism	3.11 (.82)	2.95 (.84)	.002	.201	8.19

Supplementary Table 3.4

Pairwise Associations (Pearson Correlations and Bayes Factors) Among Potential Correlates of Musical Sophistication and Musical Ability.

		2	3	4	5	6	7	8	9	10
1. Age	*r*	.204	.450	-.177	-.378	.143	.276	.180	.094	-.276
	BF_{10}	>100	>100	>100	>100	26.4	>100	>100	.753	>100
2. Gender	*r*		.095	-.023	-.080	.074	-.029	-.046	-.126	-.207
	BF_{10}		.688	.060	.346	.263	.065	.096	6.62	>100
3. Education	*r*			.125	-.261	.118	.263	.096	.062	-.170
	BF_{10}			4.41	>100	2.72	>100	.725	.155	>100
4. Cognitive Ability	*r*				.097	.010	-.055	-.025	-.060	-.023
	BF_{10}				.862	.052	.129	.061	.152	.060
5. Mind Wandering	*r*					-.046	-.626	-.174	-.241	.409
	BF_{10}					.096	>100	>100	>100	>100
6. Openness	*r*						.083	.262	.096	-.070
	BF_{10}						.409	>100	.857	.223
7. Conscientiousness	*r*							.221	.201	-.359
	BF_{10}							>100	>100	>100
8. Extroversion	*r*								.135	-.209
	BF_{10}								13.6	>100
9. Agreeableness	*r*									-.314
	BF_{10}									>100

Supplementary Table 3.5

Pairwise Correlations Among the Gold-MSI Subtests and the General Factor (N = 608).

	Perceptual Abilities	Music Training	Singing Abilities	Emotions	General Factor
Active Engagement	.562	.526	.553	.600	.735
Perceptual Abilities		.667	.740	.534	.826
Music Training			.632	.337	.863
Singing Abilities				.496	.874
Emotions					.548

Note. All p-values < .001. All BF_{10} > 100.

Supplementary Table 3.6

Associations (Pearson Correlations and Bayes Factors) Between Scores on the Gold-MSI and Demographic Variables, Cognitive Ability, Mind Wandering, and Personality.

		Active Engagement	Perceptual Abilities	Music Training	Singing Abilities	Emotions	General Factor
Age	r	.009	.088	.113	.029	-.162	.078
	BF_{10}	.052	.524	2.46	.066	>100	.314
Gender	r	.115	.094	.132	.025	-.050	.124
	BF_{10}	2.78	.734	10.3	.061	.108	5.30
Education	r	-.090	.049	.079	.014	-.088	.004
	BF_{10}	.513	.104	.306	.056	.474	.053
Cognitive Ability	r	-.062	.036	.008	.013	-.013	-.008
	BF_{10}	.164	.075	.052	.053	.054	.052
Mind-Wandering	r	-.062	-.099	-.135	-.072	.073	-.096
	BF_{10}	.160	1.01	13.6	.239	.254	.854
Openness	r	.469	.411	.405	.396	.403	.481
	BF_{10}	>100	>100	>100	>100	>100	>100
Conscientiousness	r	.040	.095	.084	.083	-.010	.071
	BF_{10}	.082	.786	.426	.420	.052	.230
Extroversion	r	.052	.113	.055	.192	.094	.119
	BF_{10}	.114	2.40	.126	>100	.744	3.88
Agreeableness	r	.101	.081	.127	.101	.148	.127
	BF_{10}	1.12	.362	6.96	1.11	40.6	6.83
Neuroticism	r	.011	-.030	-.081	-.020	.109	-.040
	BF_{10}	.053	.067	.364	.057	1.82	.082

Note. Gender was dummy-coded (Females = 0, Males = 1)

APPENDIX B

Supplementary Materials for Study 4 (Chapter 5)

Supplementary Table 5.1

Descriptive Statistics for the MET, Gold-MSI Subscales, Personality Dimensions, Cognitive Abilities, and Mind-Wandering (N = 190).

	M	*SD*	Range of Responses
MET			
Total	69.52	11.62	42 – 98
Melody	33.83	6.62	21 – 51
Rhythm	35.68	6.27	20 – 48
Gold-MSI			
Active Engagement	3.85	1.22	1.22 – 6.67
Perceptual Abilities	4.78	1.09	1.78 – 7.00
Singing Abilities	3.55	1.33	1.00 – 6.57
Emotion	5.45	0.94	2.33 – 7.00
General Factor	3.30	1.01	1.11 – 5.61
Music Practice	0.00	1.00	-0.77 – 3.53
*Duration of Practice**	1.76	1.55	1 – 7
*Compliments**	3.28	2.28	1 – 7
Identity	1.74	1.34	1 – 7
*Hours of Practice**	1.88	1.56	1 – 7
Music Theory	1.46	1.25	1 – 7
*Instruments Played**	1.42	0.74	1 – 4
Personality			
Extraversion	3.29	0.80	1.25 – 5.00
Agreeableness	3.73	0.53	2.22 – 4.89
Conscientiousness	3.53	0.69	1.67 – 5.00
Neuroticism	3.14	0.84	1.00 – 5.00
Openness	3.77	0.58	1.70 – 5.00
Cognition			
Cognitive Ability	0.61	0.15	0.25 – 0.95
Mind Wandering	3.33	0.93	1.20 – 5.80

Individual items from the Music Training subtest of the Gold-MSI (except Years of Instrumental Lessons) are in italics. *Items used to extract the principal component—Music Practice.

Supplementary Table 5.2

Descriptive Statistics for High-Ability Musically Untrained Participants (Top 20%) and Trained Participants from Correia et al. (2022). Age and Education Were Held Constant in Statistical Comparisons.

	High-Ability Untrained (n = 40)	Trained (n = 220)				
	M (SD)	M (SD)	F	p	BF_{10}	η^2
MET						
Total	85.4 (5.0)	82.0 (8.3)	5.37	.021	2.12	.020
Melody	42.2 (4.0)	42.2 (4.0)	< 1	.848	0.70	<.001
Rhythm	43.2 (3.1)	40.2 (4.5)	15.73	<.001	>100	.057
Gold-MSI						
Active Engagement	3.9 (1.2)	5.0 (0.9)	39.63	<.001	>100	.134
Perceptual Abilities	5.2 (1.1)	6.2 (0.6)	67.87	<.001	>100	.208
Singing Abilities	4.1 (1.5)	5.2 (0.9)	36.5	<.001	>100	.124
Emotion	5.7 (1.0)	6.0 (0.7)	5.93	.016	2.84	.022
General Factor	3.8 (1.2)	5.5 (0.7)	146.4	<.001	>100	.364
Music Practice	-0.6 (0.8)	0.8 (0.4)	254.1	<.001	>100	.498
Personality						
Extraversion	3.3 (0.9)	3.3 (0.8)	< 1	.918	0.19	<.001
Agreeableness	3.9 (0.5)	3.9 (0.5)	< 1	.611	0.21	.001
Conscientiousness	3.7 (0.8)	3.7 (0.7)	< 1	.479	0.24	.002
Neuroticism	3.1 (0.8)	3.0 (0.9)	1.39	.240	0.34	.005
Openness	3.8 (0.6)	4.2 (0.5)	24.97	<.001	>100	.087
Cognition						
Cognitive Ability	0.7 (0.8)	0.6 (0.7)	< 1	.399	0.25	.002
Mind Wandering	3.1 (1.0)	3.0 (0.9)	3.09	.080	0.75	.011

Supplementary Table 5.3

Descriptive Statistics for High-Ability Musically Untrained Participants (Top 30%) and Trained Participants from Correia et al. (2022). Age and Education Were Held Constant in Statistical Comparisons.

	High-Ability Untrained (n = 58)	Trained (n = 220)				
	M (SD)	M (SD)	F	p	BF_{10}	η^2
MET						
Total	83.0 (5.5)	82.0 (8.3)	< 1	.502	.191	.002
Melody	40.9 (4.1)	41.9 (5.3)	2.31	.130	.459	.008
Rhythm	42.1 (3.3)	40.2 (4.5)	9.16	.003	12.3	.033
Gold-MSI						
Active Engagement	3.8 (1.3)	5.0 (0.9)	57.91	<.001	>100	.176
Perceptual Abilities	5.1 (1.1)	6.2 (0.6)	95.78	<.001	>100	.261
Singing Abilities	3.9 (1.5)	5.2 (0.9)	64.83	<.001	>100	.193
Emotion	5.6 (0.9)	6.0 (0.7)	8.77	.003	9.66	.031
General Factor	3.6 (1.2)	5.5 (0.7)	232.45	<.001	>100	.462
Music Practice	-0.7 (0.8)	0.8 (0.4)	371.69	<.001	>100	.578
Personality						
Extraversion	3.4 (0.8)	3.3 (0.8)	< 1	.448	.215	.002
Agreeableness	3.9 (0.5)	3.9 (0.5)	< 1	.819	.165	<.001
Conscientiousness	3.6 (0.7)	3.7 (0.7)	1.65	.200	.336	.006
Neuroticism	3.0 (0.8)	3.0 (0.9)	< 1	.249	.180	<.001
Openness	3.9 (0.6)	4.2 (0.5)	22.94	<.001	>100	.078
Cognition						
Cognitive Ability	0.7 (0.8)	0.6 (0.7)	1.23	.268	.274	.005
Mind Wandering	3. (1.0)	3.0 (0.9)	5.88	.016	2.29	.021

Supplementary Table 5.4

Descriptive Statistics for High-Ability Musically Untrained Participants (Top 25%) and High-Ability Trained Participants from Correia et al. (2022). Age and Education Were Held Constant in Statistical Comparisons.

	High-Ability Untrained (n = 51)	Trained (n = 163)				
	M (SD)	M (SD)	F	p	BF_{10}	Partial η^2
MET						
Total	83.9 (5.2)	86.0 (4.8)	6.89	.009	4.10	.032
Melody	41.5 (3.9)	44.0 (3.6)	19.90	<.001	>100	.087
Rhythm	42.5 (3.2)	41.9 (3.0)	1.36	.244	.325	.007
Gold-MSI						
Active Engagement	3.9 (1.3)	5.0 (0.9)	47.11	<.001	>100	.185
Perceptual Abilities	5.1 (1.1)	6.3 (0.6)	80.36	<.001	>100	.279
Singing Abilities	4.0 (1.6)	5.3 (0.9)	56.73	<.001	>100	.214
Emotion	5.6 (1.0)	6.0 (0.7)	8.12	.005	7.18	.038
General Factor	3.7 (1.2)	5.5 (0.7)	196.42	<.001	>100	.486
Music Practice	-1.6 (1.1)	0.4 (0.5)	291.55	<.001	>100	.584
Personality						
Extraversion	3.3 (0.9)	3.4 (0.9)	< 1	.689	.188	<.001
Agreeableness	3.9 (0.4)	3.9 (0.6)	< 1	.791	.176	<.001
Conscientiousness	3.7 (0.7)	3.7 (0.7)	< 1	.329	.259	.005
Neuroticism	3.0 (0.8)	2.9 (0.9)	< 1	.594	.201	.001
Openness	3.9 (0.6)	4.2 (0.5)	19.46	<.001	>100	.086
Cognition						
Cognitive Ability	0.7 (0.8)	0.7 (0.7)	< 1	.862	.185	<.001
Mind Wandering	3.2 (1.1)	2.9 (0.9)	4.95	.027	1.57	.023