Intelligence 62 (2017) 119–124

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

Revisiting the association between music lessons and intelligence: Training effects or music aptitude?☆

Swathi Swaminathan [a], E. Glenn Schellenberg [b,*], Safia Khalil [a]

[a] Department of Psychology, University of Toronto, Toronto, ON, Canada
[b] Department of Psychology and Faculty of Music, University of Toronto, Toronto, ON, Canada

ARTICLE INFO

Article history:
Received 24 April 2016
Received in revised form 26 February 2017
Accepted 3 March 2017
Available online 15 March 2017

Keywords:
Music
Training
Intelligence
Plasticity
Gene-environment interaction

ABSTRACT

We examined whether the link between intelligence and musical expertise is better explained by formal music lessons or music aptitude. Musically trained and untrained adults completed tests of nonverbal intelligence (Raven's Advanced Progressive Matrices) and music aptitude (Musical Ear Test). They also provided information about their history of music lessons and socioeconomic status (SES). Duration of music training was associated positively with SES (mother's education), nonverbal intelligence, melody aptitude, and rhythm aptitude. Intelligence and music aptitude were also positively associated. The association between music training and intelligence remained evident after controlling for SES, but it disappeared after controlling for music aptitude. By contrast, music aptitude had a strong correlation with intelligence even after accounting for music training and SES. Thus, the association between music training and intelligence may arise because high-functioning individuals are more likely than other individuals to have good aptitude for music and to take music lessons.

1. Introduction

Musically trained children and adults score higher on intelligence tests than their untrained counterparts (dos Santos-Luiz, Mónico, Almeida, & Coimbra, 2016; Gibson, Folley, & Park, 2009; Gruhn, Galley, & Kluth, 2003; Schellenberg, 2011a, 2011b; Schellenberg & Mankarious, 2012; Trimmer & Cuddy, 2008). Moreover, as duration of training increases, so does intelligence (Corrigall & Schellenberg, 2015; Corrigall, Schellenberg, & Misura, 2013; Degé, Kubicek, & Schwarzer, 2011; Degé, Wehrum, Stark, & Schwarzer, 2014; Schellenberg, 2006). Because intelligence predicts educational achievement, occupational status, and success in dealing with the demands of daily life (e.g., Deary, Strand, Smith, & Fernandes, 2007; Gottfredson, 1997; Judge, Higgins, Thoresen, & Barrick, 1999; Spinath, Spinath, Harlaar, & Plomin, 2006), any experience that could potentially improve intelligence deserves careful study.

At present, however, there is widespread bias to interpret correlational data as evidence that music training *causes* improvements in nonmusical domains (e.g., Bugos & Mostafa, 2011; Kraus & Chandrasekaran, 2010; Skoe & Kraus, 2012; Strait & Kraus, 2011a, 2011b; Strait, Parbery-Clark, Hittner, & Kraus, 2012; Zuk, Benjamin, Kenyon, & Gaab, 2014). In other words, correlations are interpreted as evidence for far-transfer effects, such that music training is said to improve nonmusical cognitive capacities, such as intelligence, speech perception, auditory memory, or brain plasticity more generally (Herholz & Zatorre, 2012; Strait & Kraus, 2011a, 2011b; Wan & Schlaug, 2010). Although such "far-transfer" effects have been studied for over 100 years, it remains unclear whether such effects are actually possible (e.g., Brody, 1992; Jensen, 1969, 1998; Thorndike & Woodworth, 1901a, 1901b). For example, interventions designed specifically to improve working memory (Melby-Lervåg & Hulme, 2013; Rapport, Orban, Kofler, & Friedman, 2013; Shipstead, Hicks, & Engle, 2012; Weicker, Villringer, & Thöne-Otto, 2016) or academic performance (*Head Start*; Love, Chazan-Cohen, Raikes, & Brooks-Gunn, 2013) report variable or inconclusive results. Moreover, evidence that training in working memory has far-transfer effects (i.e., to reading, intelligence, arithmetic, etc.) is mixed (Melby-Lervåg, Reddick, & Hulme, 2016; Weicker et al., 2016). It is premature, then, to posit that music training would have effects on cognitive abilities when it is unclear whether interventions aimed directly at training such abilities are effective. Indeed, high-functioning individuals may be more likely than other individuals to take music lessons, or a third variable (or set of variables) may influence performance on intelligence tests *and* the likelihood of taking music lessons.

In the present correlational study, we sought to determine whether intelligence is better explained by music training or by music aptitude. If music training causes increases in intelligence (or other nonmusical abilities) that are independent of aptitude, such effects (1) should be observable as associations in correlational studies (unless the effect is miniscule and meaningless), and (2) remain evident (as partial

☆ Funded by the Natural Sciences and Engineering Research Council of Canada.
* Corresponding author at: Department of Psychology, University of Toronto Mississauga, Mississauga, ON L5L 1C6, Canada.
E-mail address: g.schellenberg@utoronto.ca (E.G. Schellenberg).

http://dx.doi.org/10.1016/j.intell.2017.03.005
0160-2896/

associations) when music aptitude is held constant. Moreover, if music training *mediates* the association between aptitude and intelligence (aptitude → training → intelligence), neither hypothesis changes. In other words, although correlation does not imply causation, causation definitely implies correlation. Aptitude could also *moderate* the association between training and intelligence. For example, such an association could be stronger or evident only among participants with relatively high levels of music aptitude.

Some experimental evidence corroborates the notion that music lessons *cause* small improvements in IQ scores. For example, when Canadian 6-year-olds were assigned randomly to 1 year of music lessons (keyboard or vocal) or to control conditions (drama lessons or no lessons; Schellenberg, 2004), pre- to post-test improvements in IQ were larger for the music groups than for the control groups. When Iranian preschoolers were assigned to 3 months of weekly music lessons or no lessons (Kaviani, Mirbaha, Pournaseh, & Sagan, 2014), only the children in the music group exhibited pre- to post-test gains in IQ. In a study of at-risk Israeli children, benefits in nonverbal intelligence were greater for children who attended after-school centers with an intensive music intervention, compared to children at a center without the intervention (Portowitz, Lichtenstein, Egorova, & Brand, 2009). Although replication across cultures is reassuring, the use of *passive* control groups (no intervention of any sort) in the Iranian and Israeli studies makes it impossible to attribute group differences to "music" rather than other aspects of the interventions. In short, unequivocal causal evidence comes from a single study. Moreover, the magnitude of the association between music training and IQ tends to be much larger in real-world (correlational) studies (dos Santos-Luiz et al., 2016; Gibson et al., 2009; Hille, Gust, Bitz, & Kammer, 2011; Schellenberg, 2011a), even when the training is only 1 or 2 years in duration (Schellenberg & Mankarious, 2012), which implicates a role for other environmental variables, or for pre-existing differences.

Positive results are further belied by mixed or null findings (e.g., François, Chobert, Besson, & Schön, 2013; Moreno et al., 2009). For example, when preschool children were assigned randomly to 6 weeks of group music lessons or no lessons at all, there was no advantage in cognitive abilities for the music group (Mehr, Schachner, Katz, & Spelke, 2013). Even correlational studies sometimes report null findings, although these could stem from small sample sizes (e.g. Corrigall & Trainor, 2011; Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011; Strait et al., 2012). Null findings are particularly likely when real musicians (e.g., graduate students in music, professional musicians) are compared to other groups with a similar amount of formal education in a field other than music (e.g., graduate students in psychology, law, or physics; Brandler & Rammsayer, 2003; Helmbold, Rammsayer, & Altenmüller, 2005; Rammsayer, Buttkus, & Altenmüller, 2012). Thus, music lessons may be a marker of cognitive ability primarily among individuals who do *not* become musicians.

Other findings reveal that genetic factors influence the propensity to practice music, as well as associations between music practice and intelligence (Mosing, Madison, Pedersen, & Ullén, 2016; Mosing, Pedersen, Madison, & Ullén, 2014), music aptitude (Mosing, Madison, Pedersen, Kuja-Halkola, & Ullén, 2014), and personality (Butkovic, Ullén, & Mosing, 2015). Music training is also correlated positively with the personality trait called *openness-to-experience* (Corrigall & Schellenberg, 2015; Corrigall et al., 2013). Individuals who are interested in learning new things (including but not limited to music) may be more likely than other individuals to take music lessons. Openness is also the personality trait that has the strongest association with intelligence (e.g., Chamorro-Premuzic & Furnham, 2008; Harris, 2004).

It is well documented that music aptitude is correlated positively with taking music lessons *and* with intelligence (for review see Schellenberg & Weiss, 2013). Aptitude is typically measured using tests of pitch and rhythm perception that require same/different judgments (Gordon, 1965; Seashore, Lewis, & Saetveit, 1960). On each trial, the listener decides whether a standard sequence (presented first) is the same as a comparison sequence (presented second). On different trials, one event in the sequence (e.g., a tone or a drum beat) is altered in pitch or time. Aptitude is considered to be a measure of natural musical ability, which predicts how successful an individual will be in musical activities. Although associations between music training and music aptitude are used to validate aptitude tests (e.g., Law & Zentner, 2012; Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010), the causal direction is unclear, and music aptitude is also a marker of intelligence in typically developing populations. In sum, associations between music training and general cognitive ability could stem primarily from pre-existing individual differences in musical ability, general cognitive ability, or personality.

In the present study, we predicted that the association between music lessons and intelligence would be explained, at least in part, by music aptitude. The distinction between aptitude and training is inherently problematic, however, because individuals with high levels of aptitude would be likely to seek out music training, which could, in turn, improve their performance on tests of music aptitude—a classic gene-environment interaction (e.g. Hambrick & Tucker-Drob, 2015; Schellenberg, 2015; Ullén, Hambrick, & Mosing, 2015). When music training *and* aptitude are measured, however, the problem is mitigated. For example, when music training is held constant, performance on a test of aptitude becomes a purer measure of pre-existing musical propensities, at least in principle if the measures accurately represent the underlying constructs. With music aptitude held constant, music training is a measure of skills and abilities *other* than basic music perception, which are acquired through training and could lead to enhanced performance in nonmusical domains, including intelligence.

2. Method

2.1. Participants

Participants were 133 undergraduate students (65 women; mean age 19.1 years, $SD = 2.2$) recruited from an introductory psychology course such that they were musically trained or untrained. Trained participants ($n = 62$, 47 women) had at least 5 years ($M = 13.91$, $SD = 7.37$) of formal music lessons taken outside of school, primarily one-on-one lessons that included instrumental training. For participants who reported training on more than one instrument, years of training were summed across instruments. Untrained participants ($n = 71$, 53 women) had *no* music training outside of school. The testing session lasted up to 90 min and participants received either $15 or $5 plus partial course credit.

Although we intended initially to treat music training as a dichotomous variable in the analyses (≥5 years vs no training), we opted to treat music training as a *continuous* variable because this approach maximized the association with nonverbal intelligence, which, in turn, made tests of the partial association between music aptitude and intelligence (i.e., with training held constant) more conservative. Responses patterns were the same, however, when music training was treated as a dichotomous variable, or as the sum of years of private *and* school-based lessons.

2.2. Measures

2.2.1. Socioeconomic status

Socioeconomic status (SES) is often associated positively with duration of music training and intelligence (e.g., Corrigall et al., 2013). Accordingly, participants were asked to provide information about their family income and their parents' education. As in previous research (Corrigall & Schellenberg, 2015; Corrigall et al., 2013; Schellenberg, 2006, 2011a, 2011b), annual family income was measured in increments of $25,000 ranging from 1 (<$25,000) to 9 (>$200,000), whereas both parents' highest level of education was measured on a scale ranging from 1 (did not complete high school) to 8 (graduate degree). The mean value was used to substitute for missing data from 14, 9, and 5 participants, respectively, for family income, mother's education, and father's education. These substitutions ensured that the same participants were included in all analyses but they had no effect on any analysis that included SES.

2.2.2. Music aptitude

Music aptitude was measured with the Musical Ear Test (MET; Wallentin et al., 2010), a valid and reliable test described by the authors as a test of musical *competence* rather than aptitude. Nevertheless, the test has a structure similar to other tests of music aptitude by providing separate scores for Melody and Rhythm (Gordon, 1965). On each trial, participants heard two short sequences and decided whether they were identical. On the Melody subtest (administered first, 52 trials, $M = 37.0$ correct, $SD = 6.0$), sequences comprised three to eight piano tones (half notes, quarter notes, or eighth notes) that conformed to the Western chromatic scale and were presented at a tempo of 100 beats per min. Some trials were tonal (i.e., all tones came from a single major or minor scale) and others atonal. On "different" trials, one of the tones was shifted in pitch. On the Rhythm subtest (52 trials, $M = 37.2$ correct, $SD = 4.7$), the participant heard two sequences of 4–11 beats of a wood-block. The underlying pulse (or meter) was fixed at 100 beats per min. Each sequence conformed to a measure but inter-onset intervals varied within each sequence. On "different" trials, one beat was displaced temporally. The entire MET took 20 min to complete.

2.2.3. Intelligence

Nonverbal intelligence was measured with set II (36 items) of the Raven's Advanced Progressive Matrices (Raven, Raven, & Court, 1998), which is considered to be one of the best single-measure proxies for *g* that is suitable for a sample of college students (e.g., Alderton & Larson, 1990; Arthur & Woehr, 1993; Marshalek, Lohman, & Snow, 1983). The test measures the ability to induce relations and consider different rules simultaneously (Carpenter, Just, & Shell, 1990).

Each item comprised a visual 3×3 matrix. All but one cell (bottom-right) contained a black-and-white geometric pattern that changed systematically but not obviously across columns and rows. Participant chose one of eight options to fill in the missing cell. Items became more difficult as the test progressed. Participants were given a maximum of 40 min to complete the test. Their score was the total number of correct responses ($M = 23.7$, $SD = 5.4$).

2.3. Procedure

After obtaining informed consent, participants completed the test of nonverbal intelligence, followed by the background questionnaire, which asked for demographic information and history of music lessons (some participants, $n = 69$, completed the background questionnaire during a previous visit to the laboratory). After a short break, participants completed the MET. All testing took place in a double-walled sound-attenuating booth (Industrial Acoustics Co.).

3. Results

A preliminary chi-square test of independence confirmed that the male-to-female ratio was similar in the musically trained and untrained groups, $p > 0.8$. Gender had no effect in any analysis and was not considered further. Tests of the SES variables used multiple regression to predict the four target variables (nonverbal intelligence, music training, melody aptitude, rhythm aptitude) as a function of mother's education, father's education, and family income. The model did not significantly predict nonverbal intelligence, $p > 0.3$, melody aptitude, $p > 0.7$, or rhythm aptitude, $p > 0.1$. It significantly predicted music training, $R = 0.27$, $F(3, 129) = 3.41$, $p = 0.020$, although only mother's education made a significant contribution to the model, $p = 0.007$. As mother's education increased, so did duration of music training, $r = 0.23$, $p = 0.008$. Thus, mother's education was used in subsequent analyses as our measure of SES.

Table 1 provides pairwise correlations for the target variables and mother's education. As expected, music training and nonverbal intelligence were positively correlated. The effect size was modest but similar in magnitude to others that have been observed previously in samples from the same population who were administered different tests of intelligence ($r = 0.24$ in Schellenberg, 2006, $r = 0.32$ in Schellenberg, 2011b; $r = 0.26$ in Corrigall et al., 2013). The association between music training and intelligence remained evident when mother's education was held constant, *pr* (partial correlation) $= 0.26$, $p = 0.002$. Other pairwise associations were consistent with expectations: (1) as duration of music training increased, scores on the melody and rhythm tests improved, (2) melody and rhythm scores were positively associated (Bhatara, Yeung, & Nazzi, 2015; Slevc, Davey, Buschkeuhl, & Jaeggi, 2016; Wallentin et al., 2010), and (3) both aptitude measures were correlated positively with nonverbal intelligence.

The main analysis used hierarchical multiple regression to model nonverbal intelligence. On the first step, predictor variables were duration of music training, the two music-aptitude variables, and mother's education (Table 2). The model explained 22.68% of the variance, multiple $R = 0.48$, $F(4, 128) = 9.39$, $p < 0.001$, virtually all of which (22.43%) involved associations with the three music variables. Both melody, $p = 0.027$, and rhythm, $p = 0.001$, made significant independent contributions to the model, but music training, $p > 0.3$, and mother's education, $p > 0.7$, did not. Most of the music-explained variance was explained by melody aptitude (3.02%), rhythm aptitude (7.14%), and the overlap between melody aptitude and rhythm aptitude (5.44%). An additional 6.20% was accounted for by overlapping variance between music aptitude and music training. The remainder (0.63%) was accounted for by music training alone.

On the second step, we examined whether music aptitude *moderated* the association between music training and intelligence. We derived two interaction variables: (1) the interaction between melody aptitude and music training, and (2) the interaction between rhythm aptitude and music training (the original variables were centered before forming the interaction variables). The addition of these two interaction variables did not significantly improve the fit of the model (Table 2), $p > 0.6$, neither interaction was significant, $ps > 0.5$, but both melody, $p = 0.024$, and rhythm, $p = 0.001$, continued to be significant predictors.

Finally, we examined whether some of the association between music aptitude and intelligence was *mediated* by music training. A bootstrap-estimation approach with 50,000 samples (Shrout & Bolger, 2002) and the PROCESS macro for SPSS (Preacher & Hayes, 2004) included music aptitude as the independent variable, nonverbal intelligence as the dependent variable, and music training as the mediator. There was no evidence for a mediation (indirect) effect, whether aptitude was considered as melody, rhythm, or the total (melody + rhythm) score (bias-corrected 95% confidence intervals: melody [−0.0476, 0.1215], rhythm [−0.0004, 0.1150], total [−0.0325, 0.0647]). In all instances, the direct association between music aptitude and nonverbal intelligence was significant, $ps < 0.001$.

Table 1
Pairwise correlations.

	Music training	Melody aptitude	Rhythm aptitude	Mother's education
Nonverbal intelligence	**0.24**	**0.38**	**0.41**	−0.05
Music training		**0.44**	**0.22**	**0.23**
Melody aptitude			**0.43**	0.01
Rhythm aptitude				−0.14

Notes. Bold font indicates $p < 0.05$.

Table 2
Hierarchical multiple regression predicting nonverbal intelligence (Raven's APM scores).

Predictor	Step 1		Step 2	
	β	*pr*	β	*pr*
Mother's education	−0.03	−0.03	−0.04	−0.04
Music training	0.09	0.09	0.06	0.06
Melody aptitude	**0.21**	**0.19**	**0.22**	**0.20**
Rhythm aptitude	**0.30**	**0.29**	**0.30**	**0.29**
Training × melody			0.06	0.06
Training × rhythm			0.04	0.04
R^2	**0.23**		**0.23**	
Adjusted R^2	**0.20**		**0.20**	
F	**9.39**		**6.37**	
ΔR^2			0.01	
ΔF			0.48	

Notes. Bold font indicates $p < 0.05$; pr = partial correlation.

4. Discussion

We examined whether duration of music training was associated with nonverbal intelligence and, if so, whether the association could be explained by music aptitude. As in previous research, nonverbal intelligence was associated positively with duration of training and with individual differences in music aptitude. Novel findings revealed that after controlling for music aptitude, the association between music training and intelligence disappeared. After controlling for music training, the association between music aptitude and intelligence remained evident. Because music training and music aptitude were correlated, some of the variance in nonverbal intelligence could not be attributed unequivocally to music training *or* to music aptitude. Nevertheless, there was no evidence that music training mediated or moderated the effect between music aptitude and intelligence.

A well-established finding in differential psychology is that individuals who perform well on one psychometric test tend to perform well on other tests, including those involving music (e.g., Carroll, 1993; Deary, 2013; Lynn & Gault, 1986; Lynn, Wilson, & Gault, 1989; Rammsayer & Brandler, 2007; Watkins, 2006). For example, when adults are administered many different tests of temporal processing, auditory perception, and general cognitive abilities, a one-factor solution emerges from principal-components analysis (Rammsayer & Brandler, 2007). This factor represents general intelligence or *g* (Spearman, 1904), with which the APM has a particularly strong association (e.g., Marshalek et al., 1983). Thus, performance on the measures of music aptitude was expected to be correlated with nonverbal intelligence, with such shared variance also involving broad second-level abilities related to auditory perception (Carroll, 1993; McGrew, 2009). Because the association between music aptitude and intelligence was evident even after holding constant music training and SES, it appears to stem primarily from pre-existing differences or from experiences other than music lessons. In any event, the association between music aptitude and intelligence was independent of the environmental variables we measured (i.e., music training and SES).

As expected, there was a simple association between music training and performance on a nonverbal test of intelligence, and the magnitude of the association was similar to those found in previous samples of participants drawn from the same population who were tested with different measures of intelligence (Corrigall et al., 2013; Schellenberg, 2006, 2011b). After controlling for music aptitude, however, the association between music lessons and intelligence disappeared. In short, a substantial part of the simple association between music training and intelligence may be the consequence of individual differences in music aptitude.

We contend that an individual's ability to function at a high level in musical as well as general contexts increases the likelihood that they will take music lessons. Rather than music training causing improvements in intelligence, the direction of causation could quite reasonably go in the opposite direction: pre-existing advantages in intelligence and music aptitude influence who takes lessons. This interpretation is consistent with findings showing that good grades in school are associated with an increased likelihood of *subsequently* taking music courses, a time-line that effectively rules out a causal role for music training (Kinney, 2008, 2010; Klinedinst, 1991).

Our phenotypical data are also consistent with two key findings from behavioral-genetics (twin) studies. First, both music aptitude and intelligence have significant genetic components that overlap to an extent. The specific genotypic structures of general intelligence and music aptitude are not well understood, but it is clear that intelligence is substantially heritable, and that the impact of genetic factors increases from childhood (heritability ≈50%) to adulthood (≈80%; Deary, 2013; Deary, Johnson, & Houlihan, 2009; Plomin & Spinath, 2004). With increasing age, individuals tend to seek out environments that match and reinforce their intellectual propensities (Scarr & McCartney, 1983). As for the genetic contribution to music aptitude, heritability estimates for melody and rhythm aptitude in adulthood are 59% and 50%, respectively (Ullén, Mosing, Holm, Eriksson, & Madison, 2014). Variation in music perception is explained by two distinct genetic components: one that overlaps with general intelligence, and another that explains variance in music aptitude but not in intelligence (Mosing, Pedersen et al., 2014). Because our melody and rhythm tests resembled the tests used in the twin studies, performance was almost certainly related to these genetic components.

Twin studies also document that genetic components underlying music aptitude and intelligence predict whether and to what extent individuals engage in musical activities (i.e., their musical environments). For example, the same genetic factors explain music aptitude and the inclination to practice music (Hambrick & Tucker-Drob, 2015; Mosing, Madison et al., 2014), which is, in turn, correlated with musical success (Ericsson, Krampe, & Tesch-Römer, 1993). When twin samples are restricted to monozygotic pairs—a design that virtually eliminates a role for genetics—twins with more music training are no more intelligent than their less-trained co-twins (Mosing et al., 2016). In the context of this literature, our findings may represent a gene-environment interaction, with early, genetically driven proclivities for general cognitive functioning and music perception increasing the likelihood of taking music lessons, which, in turn, improves performance on tests of music aptitude, and perhaps even on tests of intelligence.

We have no doubt that some of the shared variance between music training and music aptitude reflects a training effect on music perception. But if music training scaffolds on pre-existing music and general cognitive abilities, one would predict a stronger association between music aptitude and intelligence as duration of training increased. In the present study, however, variables representing the interaction between music aptitude and training had no association with nonverbal intelligence. Future research could attempt to explore this issue further with designs that maximize power to detect an interaction. Moreover, studies with larger samples and multiple measures of intelligence, music aptitude, and music training could also compare and contrast models of training effects and pre-existing differences. A more detailed mechanistic account could reveal that the association between music training and intelligence or music aptitude is attributable to individual differences in working memory or executive functions (Degé et al., 2011; Schellenberg, 2011a; Slevc et al., 2016).

Duration of music training was associated with performance on tests of melody aptitude *and* rhythm aptitude. These findings replicate and extend those reported from samples in Denmark (Wallentin et al., 2010), France (Bhatara et al., 2015), and the United States (Slevc et al., 2016), in which both melody- and rhythm-aptitude advantages were evident among musically trained participants despite marked differences across countries in how music training was operationally defined. For example, musically trained individuals in Wallentin et al. (2010) were percussionists and professional jazz and rock musicians. In Bhatara et al. (2015), the threshold for classification was simply “some music training" (e.g., 1 year), whereas Slevc et al. (2016) used continuous measures of music lessons and playing music.

In sum, the principal findings were that music lessons were not associated with intelligence after controlling for music aptitude, but music aptitude was associated with intelligence after controlling for music training. These results suggest that pre-existing individual differences in music aptitude and intelligence predict musical participation. Such participation may then go on to increase music aptitude and intelligence further, but training effects are likely to play a small role in the overall picture. Individuals who take music lessons for substantial durations of time differ from other individuals in terms of intelligence, music aptitude, SES, and personality (Corrigall & Schellenberg, 2015; Corrigall et al., 2013). Future research on music and nonmusical abilities is bound to find more interesting and nuanced results if individual differences—in music aptitude and other variables—are considered in combination with music training.

References

Alderton, D. L., & Larson, G. E. (1990). Dimensionality of Raven's advanced progressive matrices items. *Educational and Psychological Measurement*, *50*, 887–900. http://dx.doi.org/10.1177/0013164490504019.

Arthur, W., & Woehr, D. J. (1993). A confirmatory factor analytic study examining the dimensionality of the Raven's Advanced Progressive Matrices. *Educational and Psychological Measurement*, *53*, 471–478. http://dx.doi.org/10.1177/0013164493053002016.

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*, 277–282. http://dx.doi.org/10.1037/a0038736.

Brandler, S., & Rammsayer, T. H. (2003). Differences in mental abilities between musicians and non-musicians. *Psychology of Music*, *31*, 123–138. http://dx.doi.org/10.1177/0305735603031002290.

Brody, N. (1992). *Intelligence.* San Diego, CA: Academic Press.

Bugos, J., & Mostafa, W. (2011). Musical training enhances information processing speed. *Bulletin of the Council for Research in Music Education*, *187*, 7–18.

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. http://dx.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*, 404–431. http://dx.doi.org/10.1037/0033-295X.97.3.404.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies.* Cambridge, UK: Cambridge University Press.

Chamorro-Premuzic, T., & Furnham, A. (2008). Personality, intelligence and approaches to learning as predictors of academic performance. *Personality and Individual Differences*, *44*, 1596–1603. http://dx.doi.org/10.1016/j.paid.2008.01.003.

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

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

Corrigall, K. A., & Trainor, L. J. (2011). Associations between length of music training and reading skills in children. *Music Perception*, *29*, 147–155. http://dx.doi.org/10.1525/mp.2011.29.2.147.

Deary, I. J. (2013). Intelligence. *Current Biology*, *23*, R673–R676. http://dx.doi.org/10.1016/j.cub.2013.07.021.

Deary, I. J., Johnson, W., & Houlihan, L. M. (2009). Genetic foundations of human intelligence. *Human Genetics*, *126*, 215–232. http://dx.doi.org/10.1007/s00439-009-0655-4.

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

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

Degé, F., Wehrum, S., Stark, R., & Schwarzer, G. (2014). Music lessons and academic self-concept in 12- to 14-year-olds. *Musicae Scientiae*, *18*, 203–215. http://dx.doi.org/10.1177/1029864914523283.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363–406. http://dx.doi.org/10.1037/0033-295X.100.3.363.

François, C., Chobert, J., Besson, M., & Schön, D. (2013). Music training and the development of speech segmentation. *Cerebral Cortex*, *23*, 2038–2043. http://dx.doi.org/10.1093/cercor/bhs180.

Gibson, C., Folley, B. S., & Park, S. (2009). Enhanced divergent thinking and creativity in musicians: A behavioral and near-infrared spectroscopy study. *Brain and Cognition*, *69*, 162–169. http://dx.doi.org/10.1016/j.bandc.2008.07.009.

Gordon, E. (1965). The Musical Aptitude Profile: A new and unique musical aptitude test battery. *Bulletin of the Council for Research in Music Education*, *6*, 12–16.

Gottfredson, L. S. (1997). Why *g* matters: The complexity of everyday life. *Intelligence*, *24*, 79–132. http://dx.doi.org/10.1016/S0160-2896(97)90014-3.

Gruhn, W., Galley, N., & Kluth, C. (2003). Do mental speed and musical abilities interact? *Annals of the New York Academy of Sciences*, *999*, 485–496. http://dx.doi.org/10.1196/annals.1284.059.

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

Harris, J. A. (2004). Measured intelligence, achievement, openness to experience, and creativity. *Personality and Individual Differences*, *36*, 913–929. http://dx.doi.org/10.1016/S0191-8869(03)00161-2.

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

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

Hille, K., Gust, K., Bitz, U., & Kammer, T. (2011). Associations between music education, intelligence, and spelling ability in elementary school. *Advances in Cognitive Psychology*, *7*, 1–6. http://dx.doi.org/10.2478/v10053-008-0082-4.

Jensen, A. R. (1969). How much can we boost I.Q. and scholastic achievement? *Harvard Educational Review*, *33*, 1–123. http://dx.doi.org/10.17763/haer.39.1.l3u15956627424k7.

Jensen, A. R. (1998). *The g factor.* Westport: Praeger Publishers.

Judge, T. A., Higgins, C. A., Thoresen, C. J., & Barrick, M. R. (1999). The big five personality traits, general mental ability, and career success across the life span. *Personnel Psychology*, *52*, 621–652. http://dx.doi.org/10.1111/j.1744-6570.1999.tb00174.x.

Kaviani, H., Mirbaha, H., Pournaseh, M., & Sagan, O. (2014). Can music lessons increase the performance of preschool children in IQ tests? *Cognitive Processing*, *15*, 77–84. http://dx.doi.org/10.1007/s10339-013-0574-0.

Kinney, D. W. (2008). Selected demographic variables, school music participation, and achievement test scores of urban middle school students. *Journal of Research in Music Education*, *56*, 145–161. http://dx.doi.org/10.1177/0022429408322530.

Kinney, D. W. (2010). Selected nonmusic predictors of urban students' decisions to enroll and persist in middle school band programs. *Journal of Research in Music Education*, *57*, 334–350. http://dx.doi.org/10.1177/0022429409350086.

Klinedinst, R. E. (1991). Predicting performance achievement and retention of fifth-grade instrumental students. *Journal of Research in Music Education*, *39*, 225–238. http://dx.doi.org/10.2307/3344722.

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

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

Love, J. M., Chazan-Cohen, R., Raikes, H., & Brooks-Gunn, J. (2013). What makes a difference: Early Head Start evaluation findings in a developmental context. *Monographs of the Society for Research in Child Development*, *78*, 1–173. http://dx.doi.org/10.1111/j.1540-5834.2012.00699.x.

Lynn, R., & Gault, A. (1986). The relation of musical ability to general intelligence and the major primaries. *Research in Education*, *36*, 59–64.

Lynn, R., Wilson, R. G., & Gault, A. (1989). Simple musical tests as measures of Spearman's g. *Personality and Individual Differences*, *10*, 25–28. http://dx.doi.org/10.1016/0191-8869(89)90173-6.

Marshalek, B., Lohman, D. F., & Snow, R. E. (1983). The complexity continuum in the radex and hierarchical models of intelligence. *Intelligence*, *7*, 107–127. http://dx.doi.org/10.1016/0160-2896(83)90023-5.

McGrew, K. S. (2009). CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research. *Intelligence*, *37*, 1–10. http://dx.doi.org/10.1016/j.intell.2008.08.004.

Mehr, S. A., Schachner, A., Katz, R. C., & Spelke, E. S. (2013). Two randomized trials provide no consistent evidence for nonmusical cognitive benefits of brief preschool music enrichment. *PloS One*, *8*(12), e82007. http://dx.doi.org/10.1371/journal.pone.0082007.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, *49*, 270–291. http://dx.doi.org/10.1037/a0028228.

Melby-Lervåg, M., Reddick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far transfer". *Perspectives on Psychological Science*, *11*, 512–534. http://dx.doi.org/10.1177/1745691616635612.

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

Mosing, M. A., Madison, G., Pedersen, N. L., Kuja-Halkola, R., & Ullén, F. (2014a). Practice does not make perfect: No causal effect of music practice on music ability. *Psychological Science*, *25*, 1795–1803. http://dx.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*, 504–512. http://dx.doi.org/10.1111/desc.12306.

Mosing, M. A., Pedersen, N. L., Madison, G., & Ullén, F. (2014b). Genetic pleiotropy explains associations between musical auditory discrimination and intelligence. *PloS One*, *9*(11), e113874. http://dx.doi.org/10.1371/journal.pone.0113874.

Parbery-Clark, A., Strait, D. L., Anderson, S., Hittner, E., & Kraus, N. (2011). Musical experience and the aging auditory system: Implications for cognitive abilities and hearing speech in noise. *PloS One*, *6*(5), e18082. http://dx.doi.org/10.1371/journal.pone.0018082.

Plomin, R., & Spinath, F. M. (2004). Intelligence: Genetics, genes, and genomics. *Journal of Personality and Social Psychology*, *86*, 112–129. http://dx.doi.org/10.1037/0022-3514.86.1.112.

Portowitz, A., Lichtenstein, O., Egorova, L., & Brand, E. (2009). Underlying mechanisms linking music education and cognitive modifiability. *Research Studies in Music Education*, *31*, 107–128. http://dx.doi.org/10.1177/1321103X09344378.

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers*, *36*, 717–731. http://dx.doi.org/10.3758/BF03206553.

Rammsayer, T. H., & Brandler, S. (2007). Performance on temporal information processing as an index of general intelligence. *Intelligence*, *35*, 123–139. http://dx.doi.org/10.1016/j.intell.2006.04.007.

Rammsayer, T. H., Buttkus, F., & Altenmüller, E. (2012). Musicians do better than nonmusicians in both auditory and visual timing tasks. *Music Perception*, *30*, 85–96. http://dx.doi.org/10.1525/mp.2012.30.1.85.

Rapport, M. D., Orban, S. A., Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review*, *33*, 1237–1252. http://dx.doi.org/10.1016/j.cpr.2013.08.005.

Raven, J., Raven, J. C., & Court, J. H. (1998). *Advanced progressive matrices.* San Antonio, TX: Harcourt Assessment.

dos Santos-Luiz, C., Mónico, L. S., Almeida, L. S., & Coimbra, D. (2016). Exploring the long-term associations between adolescents' music training and academic achievement. *Musicae Scientiae*, *20*, 512–527. http://dx.doi.org/10.1177/1029864915623613.

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

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

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

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

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

Schellenberg, E. G. (2015). Music training and speech perception: A gene–environment interaction. *Annals of the New York Academy of Sciences*, *1337*, 170–177. http://dx.doi.org/10.1111/nyas.12627.

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

Schellenberg, E. G., & Weiss, M. W. (2013). Music and cognitive abilities. In D. Deutsch (Ed.), *The psychology of music* (pp. 499–550) (3rd ed.). Amsterdam: Elsevier.

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

Shipstead, Z., Hicks, K. L., & Engle, R. W. (2012). Cogmed working memory training: Does the evidence support the claims? *Journal of Applied Research in Memory and Cognition*, *1*, 185–193. http://dx.doi.org/10.1016/j.jarmac.2012.06.003.

Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods*, *7*, 422–445. http://dx.doi.org/10.1037//1082-989X.7.4.422.

Skoe, E., & Kraus, N. (2012). A little goes a long way: How the adult brain is shaped by musical training in childhood. *The Journal of Neuroscience*, *32*, 11507–11510. http://dx.doi.org/10.1523/JNEUROSCI.1949-12.2012.

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. http://dx.doi.org/10.1016/j.cognition.2016.03.017.

Spearman, C. (1904). "General intelligence," objectively determined and measured. *American Journal of Psychology*, *15*, 201–293.

Spinath, B., Spinath, F. M., Harlaar, N., & Plomin, R. (2006). Predicting school achievement from general cognitive ability, self-perceived ability, and intrinsic value. *Intelligence*, *34*, 363–374. http://dx.doi.org/10.1016/j.intell.2005.11.004.

Strait, D. L., & Kraus, N. (2011a). Can you hear me now? Musical training shapes functional brain networks for selective auditory attention and hearing speech in noise. *Frontiers in Psychology*, *2*, 113. http://dx.doi.org/10.3389/fpsyg.2011.00113.

Strait, D., & Kraus, N. (2011b). Playing music for a smarter ear: Cognitive, perceptual and neurobiological evidence. *Music Perception*, *29*, 133–146. http://dx.doi.org/10.1525/mp.2011.29.2.133.

Strait, D. L., Parbery-Clark, A., Hittner, E., & Kraus, N. (2012). Musical training during early childhood enhances the neural encoding of speech in noise. *Brain and Language*, *123*, 191–201. http://dx.doi.org/10.1016/j.bandl.2012.09.001.

Thorndike, E. L., & Woodworth, R. S. (1901a). The influence of improvement in one mental function upon the efficiency of other functions. II. The estimation of magnitudes. *Psychological Review*, *8*, 384–395. http://dx.doi.org/10.1037/h0071280.

Thorndike, E. L., & Woodworth, R. S. (1901b). The influence of improvement in one mental function upon the efficiency of other functions: III. Functions involving attention, observation and discrimination. *Psychological Review*, *8*, 553–564. http://dx.doi.org/10.1037/h0071363.

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

Ullén, F., Hambrick, D. Z., & Mosing, M. A. (2015). Rethinking expertise: A multifactorial gene–environment interaction model of expert performance. *Psychological Bulletin*, *142*, 427–446. http://dx.doi.org/10.1037/bul0000033.

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.

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*, 188–196. http://dx.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 life span. *The Neuroscientist*, *16*, 566–577. http://dx.doi.org/10.1177/1073858410377805.

Watkins, M. W. (2006). Orthogonal higher order structure of the Wechsler Intelligence Scale for Children- Fourth Edition. *Psychological Assessment*, *18*, 123–125. http://dx.doi.org/10.1037/1040-3590.18.1.123.

Weicker, J., Villringer, A., & Thöne-Otto, A. (2016). Can impaired working memory functioning be improved by training? A meta-analysis with a special focus on brain injured patients. *Neuropsychology*, *30*, 190–212. http://dx.doi.org/10.1037/neu0000227.

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PloS One*, *9*(6), e99868. http://dx.doi.org/10.1371/journal.pone.0099868.