HHS Public Access
Author manuscript
Psychol Aesthet Creat Arts. Author manuscript; available in PMC 2024 December 01.

Published in final edited form as:
Psychol Aesthet Creat Arts. 2023 December ; 17(6): 675–681. doi:10.1037/aca0000401.

Music and verbal ability – a twin study of genetic and environmental associations

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Abstract

Musical aptitude and music training are associated with language-related cognitive outcomes, even when controlling for general intelligence. However, genetic and environmental influences on these associations have not been studied, and it remains unclear whether music training can causally increase verbal ability. In a sample of 1,336 male twins, we tested the associations between verbal ability measured at time of conscription at age 18 and two music related variables: overall musical aptitude and total amount of music training before the age of 18. We estimated the amount of specific genetic and environmental influences on the association between verbal ability and musical aptitude, over and above the factors shared with general intelligence, using classical twin modelling. Further, we tested whether music training could causally influence verbal ability using a co-twin-control analysis. Musical aptitude and music training were significantly associated with verbal ability. Controlling for general intelligence only slightly attenuated the correlations. The partial association between musical aptitude and verbal ability, corrected for general intelligence, was mostly explained by shared genetic factors (50%) and non-shared environmental influences (35%). The co-twin-control-analysis gave no support for causal effects of early music training on verbal ability at age 18. Overall, our findings in a sizeable population sample converge with known associations between the music and language domains, while results from twin modelling suggested that this reflected a shared underlying aetiology rather than causal transfer.

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The last two authors share senior authorship.

The authors declare no conflicts of interest with respect to the authorship or the publication of this article.

Introduction

Music training and musical aptitude show positive associations with performance on a broad range of cognitive tasks (Schellenberg & Weiss, 2013). Music training is correlated, as one would expect, with performance on tests of music cognition (Ullén, Mosing, Holm, Eriksson, & Madison, 2014; Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010), but correlations have also been reported with, for example, visuospatial (Hetland, 2000; Sluming, Brooks, Howard, Downes, & Roberts, 2007) and mathematical abilities (Hobbs, 1985; Vaughn, 2000). Attention has also been given to the association between music and the language domain (Besson, Barbaroux, & Dittinger, 2017; Kraus & White-Schwoch, 2017; Patel, 2007; Peretz, Vuvan, Lagrois, & Armony, 2015). Music training is associated with measures of verbal memory (Chan, Ho, & Cheung, 1998; Schellenberg & M.W. Weiss, 2013), vocabulary (Moreno et al., 2011; Piro & Ortiz, 2009), auditory cognition (Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011) and reading skills (Butzlaff, 2000; Moreno et al., 2009). Similarly to music training, musical aptitude shows small to modest positive associations with language tasks, including phonological awareness (Anvari, Trainor, Woodside, & Levy, 2002; Forgeard et al., 2008; Jones, Lucker, Zalewski, Brewer, & Drayna, 2009; Politimou, Dalla Bella, Farrugia, & Franco, 2019), reading (Anvari et al., 2002; Forgeard et al., 2008), pronunciation (Milovanov & Tervaniemi, 2011), speech encoding (Mankel & Bidelman, 2018) and spoken grammar (Gordon, Shivers, et al., 2015). Further, several studies comparing musicians versus non-musicians reported speech processing abilities (like vowel perception or pitch processing) to be higher in musicians (Bidelman & Alain, 2015; Magne, Schon, & Besson, 2006; Marie, Magne, & Besson, 2011; Schon, Magne, & Besson, 2004). However, associations between music and language have rarely been tested in large population samples.

It could be that music and language share evolutionary roots (Brown, Martinez, & Parsons, 2006; Kotz, Ravignani, & Fitch, 2018; Wallin, Merker, & Brown, 2000), which would be reflected in phenotypic as well as genetic correlations. For instance, it has been proposed that a rudimentary form of singing communication pre-dated language (Brown, 2017; Dissanayake, 2005; Mithen, Morley, Wray, Tallerman, & Gamble, 2006). Other theorists have suggested that generic mechanisms for processing of hierarchical structures in the brain may have played a key role in the evolution of both music and language (Fitch, 2017; Fitch & Martins, 2014). Yet at present, the hypothesis that language and music share a genetic basis is largely unexplored.

To summarize, even though associations between measures of music training or musical aptitude, on the one hand, and language related cognitive outcomes, on the other hand, are well-replicated, less is known about their underlying causes. In addition, intervention studies have also found significant effects of music training on verbal performance and neural processing of linguistic stimuli, providing indications that music and language could be causally related (Chobert, Francois, Velay, & Besson, 2014; Moreno et al., 2009; Yu et al., 2017). This evidence has largely been interpreted in favor of a causal transfer hypothesis of expertise from music training to language skills (see OPERA hypothesis by Patel, 2014). However, the observed associations could also be driven by genetic liability or environmental factors, rather than causal effects of one on the other. For example, both music training and musical aptitude are correlated with general intelligence (Mosing, Madison, Pedersen, & Ullén, 2016; Mosing, Pedersen, Madison, & Ullén, 2014; Mosing, Verweij, Madison, & Ullén, 2016; Schellenberg & Weiss, 2013), which in turn is related to performance on essentially all cognitive tasks (McGrew, 2009). We have found, using twin modelling, that shared genes underlie associations between intelligence and musical outcomes (Mosing, Madison, et al., 2016; Mosing et al., 2014; Mosing, Verweij, et al., 2016) and a high genetic correlation has been found between intelligence and language abilities (Plomin & Deary, 2015). Nonetheless, an emerging literature shows that correlations between language tasks and musical tasks, or music training, remain significant when general intelligence is held constant (Barwick, Valentine, West, & Wilding, 1989; Corrigall & Trainor, 2011; Gordon, Shivers, et al., 2015; Lamb & Gregory, 1993; Milovanov & Tervaniemi, 2011; Swaminathan & Schellenberg, 2019). This suggests that associations between musical and verbal abilities are likely influenced by more specific factors, over and above the effects of general intelligence.

In this study, we analyzed the associations between musical variables and verbal ability, taking general intelligence into account, utilizing a large sample of Swedish twins. The study had three specific aims. First, we test whether, in our population-based twin sample, musical aptitude is correlated with verbal ability, even when controlling for general intelligence. Second, with the use of twin data, we will test to what degree the association between musical aptitude and verbal ability is influenced by specific genetic factors, over and above the genetic factors shared with general intelligence. Lastly, we will investigate whether a cumulative measure of music training during childhood and adolescence is correlated with verbal ability measured in early adulthood and whether this association remains significant within monozygotic twin pairs, i.e. a co-twin-control analysis, to test whether the association is in line with a causal hypothesis.

Methods

Participants

In 2012–2013, 32,000 adult twins registered with the Swedish Twin Registry (STR) from ‘the Study of Twin Adults: Genes and Environment’ (STAGE) were invited to participate in a study collecting, among other things, data on music training, musical aptitude and general intelligence. The 11,543 twin individuals that responded (4,891 males) were aged between 27 and 54 years (M = 40.7, DS = 7.7) at time of measurement. Of the 4,891 male participants, 2,288 had completed an intelligence test, including a verbal ability measurement, at age 18 based on military conscription measures. Of these 2,288 individuals, 1,336 individuals (480 monozygotic [MZ] twins) had data available on musical aptitude and 1,472 (525 MZ twins) on hours of music training. These were used for phenotypic correlations and co-twin-control analysis. Data from complete twin pairs contribute to the genetic analyses, and were available for verbal ability for 303 pairs (185 MZ and 118 dizygotic [DZ] twin pairs), for musical aptitude for 373 pairs (240 MZ, 133 DZ twin pairs), and for general intelligence for 507 pairs (310 MZ, 197 DZ twin pairs). In total, for 165 complete male twin pairs (110 MZ, 55 DZ twin pairs) information was available on all three measures: verbal ability, musical aptitude and general intelligence.

Informed consent was obtained from all participants. The study was approved by the Regional Ethics Review Board in Stockholm (Dnr 2011/570-31/5, 2012/1107-32, 2018/1592-32). All research methods were performed in accordance with relevant guidelines and regulations.

Measures

Musical aptitude.—Musical aptitude was measured using the Swedish Musical Discrimination Test (SMDT) (Ullén et al., 2014). The SMDT, administered online, consists of three subtests: a pitch, melody and rhythm discrimination test. The three discrimination scores encompass different trials ranging from 18 to 27 trials. Cronbach's alpha values were in the range .79–.89 for all scales; see Ullén et al. (2014) for a more detailed description and psychometric validation of the SMDT. Here, the mean of the three standardized subtest scores was used as an overall musical aptitude score.

General intelligence.—Psychometric intelligence was measured with the Wiener Matrizen Test (WMT) (Formann & Piswanger, 1979), which is a visual matrix test similar to Raven's standard progressive matrices. WMT scores correlate highly with Raven's SPM ($r =$ 0.92) and a Cronbach's alpha of .79 shows a relative high reliability of the scale (Ullén et al., 2012). The 25-minute long test consists of 24 multiple choice items and correctly answered items are scored as one and summed, while incorrect or missing items are scored as zero.

Verbal ability.—The Swedish military service examines men before the beginning of their conscription. The Swedish Enlistment Battery (Carlstedt & Mårdberg, 1993; Mårdberg & Carlstedt, 1998) includes a cognitive ability (IQ) test that consists of four different parts that measure logical (40 items), spatial (25 items), verbal (40 items) and technical abilities (52 items). The verbal ability subtest measured verbal comprehension and was administered in two different versions. One was a concept discrimination test in which participants had to select which word does not fit with the others conceptually, out of a list of five words; in the other version, participants had to select the synonym to a word from four alternatives. Normed scores from the two versions were pooled in the present analyses. Previous studies indicate that the verbal subscale loads substantially on both a second-order verbal-crystallized intelligence factor (Gc) and general intelligence (g) (Carlstedt & Mårdberg, 1993). A Cronbach's alpha of .88 has been reported for the verbal subscale (Rönnlund, Carlstedt, Blomstedt, Nilsson, & Weinehall, 2013). Instructions are given prior to each subtest and participants are asked to proceed as fast as possible. Results of the different tests performed are summed into a 9-point scale, 1 to 9.

Musical training.—Participants that ever played an instrument were asked to indicated the years they played and the number of hours per week they practiced music (in 10 categories ranging from 0, over 6–9, to more than 40 hours) during four age intervals (ages 0–5, 6–11, 12–17 and 18 years until time of measurement). From these answers, a score reflecting cumulative music training from the moment they started practicing until age 18 was calculated (Mosing, Madison, Pedersen, Kuja-Halkola, & Ullen, 2014).

All variables included in the analyses were standardized with a mean of zero and a standard deviation of one.

Statistical analyses

Phenotypic associations—*Correlations* between verbal ability, musical aptitude, music training before the age of 18, and general intelligence were calculated in STATA. Additionally, we calculated partial correlations controlling for general intelligence.

Genetic and environmental influences on the relationship between musical aptitude and verbal ability Bivariate classical twin modelling – a Cholesky decomposition – in OpenMx (Boker et al., 2011) was performed to explore the genetic and environmental influences, on the association between musical aptitude and verbal ability, while controlling for general intelligence. Therefore, in the model, we entered a residual score for musical aptitude and a residual score for verbal ability, after having regressed general intelligence out. In this genetic structural equation model, the observed phenotypic variance (based on the correlations between twin 1 and twin 2 for the studied traits) as well as the phenotypic covariance (based on the cross-twin-cross-trait correlations between the traits) can be partitioned into additive genetic (A), common environmental (C) and non-shared environmental (E) components. This is possible because of the availability of data from two types of twins: MZ twins who share 100% of their genetic material and family environment, and DZ twins who share, on average, 50% of their genes and 100% of their family environment (Verweij, Mosing, Zietsch, & Medland, 2012). We estimated the ACE influences on the association between musical aptitude and verbal ability, controlling for general intelligence. The significance of these ACE influences on the association was tested using the likelihood-ratio test, by comparing a model with the genetic or environmental factor freely estimated to a model with the genetic or environmental factor constrained to zero. In the likelihood ratio test, the negative log-likelihood (−2LL) and the degrees of freedom (df) of the more constrained model are subtracted from the −2LL and df of the more general model. A chi square test then shows whether the constraint significantly deteriorates the fit of the model ($p<.01$).

Testing potential causality of effects of music training on verbal ability—*Co-twin control analyses* in MZ twins were conducted to test whether the association between music training before the age of 18 and verbal ability measured at conscription remained significant when controlling for shared genetic and shared environmental factors influencing both traits. Since MZ twins share their genetic make-up as well as their common family environment, associations within such pairs are in theory free from familial confounding. In case of a causal association, the twin with more music training would be expected to also score higher on verbal ability than his or her co-twin, who trained less. Within-pair linear regression analyses were conducted using the *xtreg fe* statement in STATA to stratify by twin pair. Only complete MZ twin pairs discordant in music training and verbal ability contribute to the within-pair analyses. The analyses were adjusted for general intelligence.

Results

Phenotypic associations

In Table 1, above the diagonal, we show the correlations between musical aptitude, verbal ability, music training and general intelligence. Below the diagonal, partial correlations, i.e. controlled for general intelligence, are displayed. Supplementary Figure 1 shows the associations between musical aptitude and verbal ability ($r = .36$), music training and verbal ability ($r = .11$) and their best linear fit when adjusting for general intelligence (.25 and .08 respectively). For a complete correlation table of all measured variables (musical aptitude subscales, other subtests of the conscription IQ test), see Supplementary Table 1.

Genetic and environmental influences on the relationship between musical aptitude and verbal ability

Twin correlations and their 95% confidence intervals are shown in Supplementary Table 2. For all traits, MZ correlations were higher than DZ correlations, suggesting the involvement of additive genetic factors. The DZ correlations were larger than half of the MZ correlations, also suggesting a role for the common environment.

Based on the Cholesky decomposition, we calculated the percentage of the association between musical aptitude and verbal ability explained by genetic and environmental influences. Of the phenotypic correlation between musical aptitude and verbal ability ($r = .25$; when controlling for general intelligence), 50% of the variance was explained by genetic factors, 15% by common environmental factors and 35% by unique environmental factors.

Figure 1 shows the path estimates and their confidence intervals for the bivariate model including musical aptitude and verbal ability controlled for general intelligence. Non-significant paths are dashed and path estimates for the unique environmental influences are displayed in light grey. Even though genetic factors explained the majority of the covariance between musical aptitude and verbal ability, significance testing showed that the genetic pathway from musical aptitude to verbal ability, denoting shared genetic factors independent of general intelligence, could be constrained to 0 without significant deterioration of model fit (χ^2 0.83 (1), p= .36). The shared environmental pathways from musical aptitude to verbal ability was also non-significant (χ^2 0.09 (1), p=.76).

Testing potential causality of effects of music training on verbal ability

Within-pair linear regressions in identical twin pairs (co-twin control analyses) showed no significant effect of music training on verbal ability (β = .05, p =.56), when adjusting for familiar factors. When adding general intelligence to the analyses the results did not change (β = .07, p =.42).

Discussion

Here, we tested three hypotheses concerning the associations between musical aptitude, music training and verbal abilities in a large population-based sample (N=1,336 male individuals in the Swedish Twin Registry). In support of our first hypothesis, we found that musical aptitude and music training were associated with verbal ability, even when controlling for general intelligence. Second, we used twin modelling to test whether the association between musical aptitude and verbal ability depends on specific genetic factors, over and above influences from general intelligence. This hypothesis was partly confirmed by the data: the partial association between musical aptitude and verbal ability was mostly explained by genetic influences. However, this finding did not reach statistical significance. Thirdly, we tested if music training in childhood and adolescence has a causal influence on verbal ability measured at age 18. Co-twin control modelling provided no support for this hypothesis.

The correlation between musical aptitude and verbal ability was moderate (.36) and largely remained when controlling for general intelligence (.25). These results converge with findings from a variety of neuropsychological studies showing associations between music and language related traits, while controlling for intelligence (Barwick et al., 1989; Corrigall & Trainor, 2011; Gordon, Shivers, et al., 2015; Hille, Gust, Bitz, & Kammer, 2011; Lamb & Gregory, 1993; Milovanov & Tervaniemi, 2011; Swaminathan & Schellenberg, 2019). Surprisingly, general intelligence only slightly attenuated the correlations, while we expected a larger role for IQ in explaining covariance between language abilities and musical aptitude based on the well-established association between music and IQ (Schellenberg & Weiss, 2013).

Nevertheless, as the association between musical aptitude and verbal ability remained significant after controlling for general intelligence, we were able to investigate its underlying genetic and environmental influences. The association between music aptitude and verbal ability was mostly driven by genetic factors; however, this effect was non-significant. It is important to note though that the lack of statistical significance is likely due to the small sample size of complete male twin pairs with data available for all three traits (N=165 twin pairs). The size of the path estimates indicated that the most prominent influence on the partial variance (corrected for general intelligence) was that of the genetic factor. Therefore, it seems that for musical aptitude there are specific genetic influences, over and above the genetic influences shared with general intelligence, that explain the association with verbal ability. This could imply that individuals with a genetic predisposition for music are also more likely to have a predisposition for better language skills. Notably, we also found a significant non-shared environmental component in the association, suggesting that there may also be overlapping environmental influences on musical and verbal ability. To further investigate such environmental factors (e.g., genetic niche picking) will be an interesting topic for further research.

The last hypothesis was whether there was a potentially causal influence of music training on verbal ability. First, we found that music practice in childhood and adolescence is slightly but significantly associated with verbal ability (r=.11 or .08 when controlled for general intelligence). This finding aligns with a substantial body of evidence showing that individuals who practice music tend to have better abilities and sensitivities for speech and language (i.e., Brod & Opitz, 2012; Marie et al., 2011; Schon et al., 2004). One possibility is that this would represent causal transfer effects from music training to language skills (see e.g. OPERA hypothesis, Patel, 2014). However, the present co-twin control analysis showed that music training during childhood and adolescence, when controlling for familial confounding, did not predict verbal ability at age of conscription. This suggests that the association between music practice and verbal ability is largely driven by familial factors, which is in line with findings from Swaminathan and Schellenberg (2019). Moreover, adding general intelligence to the analysis did not change these results. Therefore, in earlier correlational work (i.e., Musacchia et al., 2007; Marie et al., 2011; Bidelman & Alain, 2015), associations between voluntary music training and verbal abilities are likely to be influenced by familial factors making individuals and their families who seek music training more predisposed to better music and speech/language acquisition skills (Mankel & Bidelman, 2018, Schellenberg, 2015).

This study has several limitations. First, our data on verbal ability were limited to men enrolled in the Swedish military service before the beginning of their conscription. Therefore, it is possible that individuals may have purposefully underperformed in the tests to avoid conscription, which would result in increased error and as such in reduced associations with the later collected phenotypes. More importantly, this sample therefore only includes males; future research should test whether our findings replicate for females. Second, as mentioned earlier, the sample of complete male twin pairs with data available for musical aptitude, verbal ability and general intelligence was small (N=165 pairs) – presumably an important explanation for the non-significant pathways in our genetic model. Third, the hours of music training variable was based on self-report data and this could introduce a bias. Another important point is that we studied the amount of any kind of voluntary music training which can vary largely depending on e.g. whether an individual sings or the instrument the individual plays. Possibly, focused and controlled training of specific musical tasks in the context of an intervention, as for example in the study by Francois, Chobert, Besson, and Schon (2013), could have different and larger effects on language task performance. Lastly, it is important to emphasize that verbal ability measured in this study reflects lexical access and semantic relationships, which is only one component of the much broader ‘language construct’. It would be valuable if in the future, other aspects of language (for example grammar or phonological awareness) in relation to musical aptitude would also be explored in genetically informative samples. The strength of this study is that we had a large population-based sample in which we were able to investigate not only the phenotypic association between musical aptitude, music training and verbal ability, but also test whether this association could be causal, by taking genetic and familial confounding into account.

To our knowledge, the present study is the first genetically informative population-based study that has now demonstrated that musical aptitude and music training are indeed associated with verbal abilities in a population-based sample, even when controlling for general intelligence. Both genetic and non-shared environmental factors are involved in the partial association, corrected for influences from general intelligence, between musical aptitude and verbal ability. Rather than finding a causal effect of music training, our findings suggest that the association between music training and verbal ability is likely due to shared underlying aetiology.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements:

The present work was supported by the Bank of Sweden Tercentenary Foundation (M11-0451:1), the Sven and Dagmar Salén Foundation and the Marcus and Amalia Wallenberg Foundation (MAW 2018.0017). We acknowledge The Swedish Twin Registry for access to data. The Swedish Twin Registry is managed by Karolinska Institutet and receives funding through the Swedish Research Council under the grant no 2017–00641. Reyna L. Gordon was supported by funding from the National Institute on Deafness and Other Communication Disorders and the Office of the Director of the National Institutes of Health under award numbers K18DC017383 and R01DC016977. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

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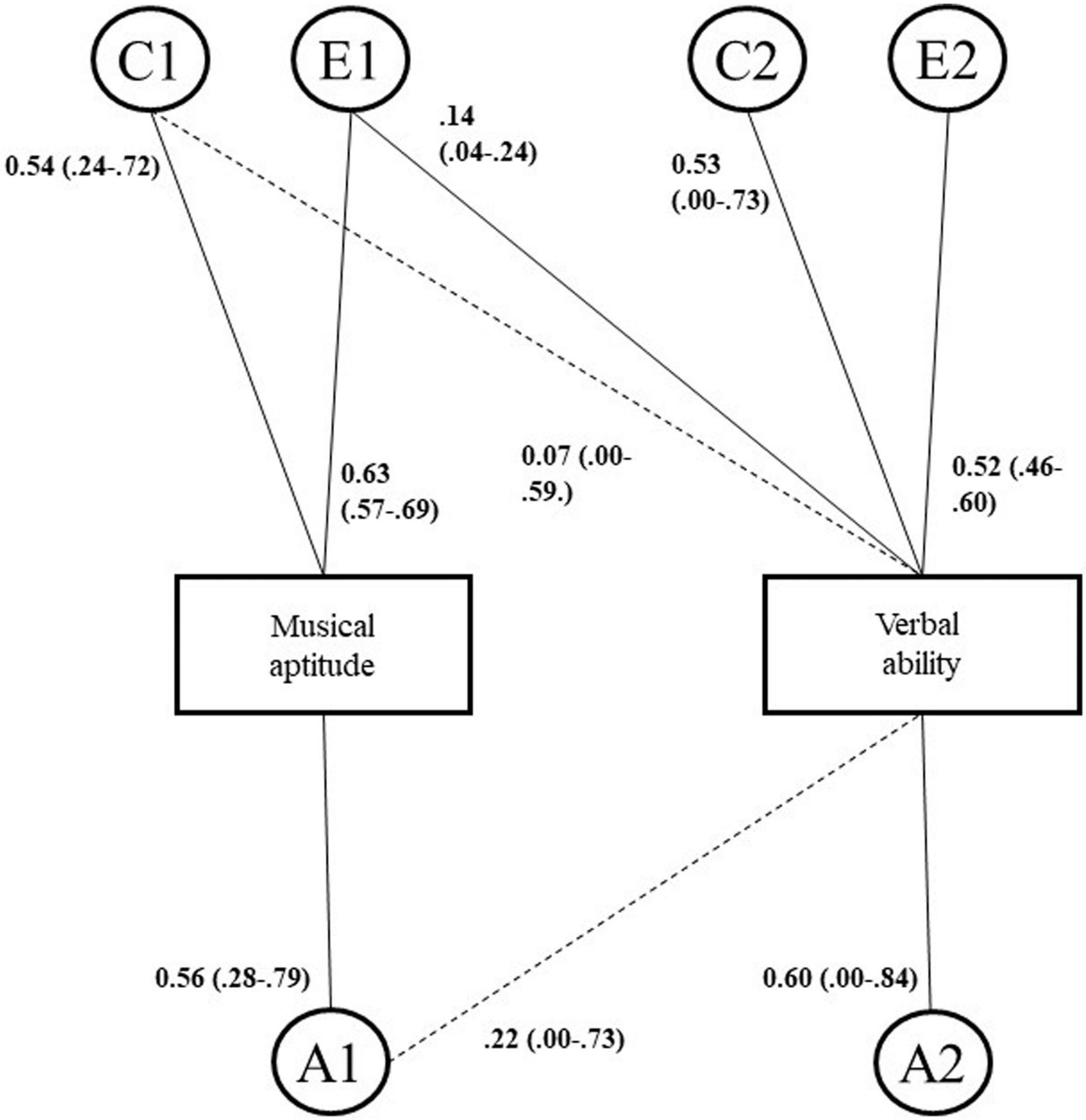

Figure 1.
The bivariate Cholesky decomposition for musical aptitude and verbal ability, adjusted for general intelligence. A1 and A2 are the additive genetic factors with their pathway estimates; C1, C2, E1 and E2 are the common (C) and unique (E) environmental factors, respectively. Dashed lines indicate non-significant paths. The sample of complete male twin pairs with data available for musical aptitude, verbal ability and general intelligence was n=165.

Table 1.

Correlations (n) between musical aptitude, verbal ability, music training before 18 and general intelligence. Raw correlations are shown above the diagonal and partial correlations, controlling for general intelligence, are shown below the diagonal.

	Music aptitude	Verbal ability	Music training	General intelligence
Musical aptitude	-	.36** (N=1,336)	.35** (N=1,742)	.38** (N=2,830)
Verbal ability	.25** (N=1,334)	-	.11** (N=1,305)	.38** (N=1,689)
Music training	.35** (N=1,740)	.08* (N=1,007)	-	.07* (N=2,187)

** $p<.001$,

* $p<.05$.