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PAPER

Investigating cognitive transfer within the framework of music practice: genetic pleiotropy rather than causality

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Abstract

*The idea of far transfer effects in the cognitive sciences has received much attention in recent years. One domain where far transfer effects have frequently been reported is music education, with the prevailing idea that music practice entails an increase in cognitive ability (IQ). While cross-sectional studies consistently find significant associations between music practice and IQ, randomized controlled trials, however, report mixed results. An alternative to the hypothesis of cognitive transfer effects is that some underlying factors, such as shared genes, influence practice behaviour and IQ causing associations on the phenotypic level. Here we explored the hypothesis of far transfer within the framework of music practice. A co-twin control design combined with classical twin-modelling based on a sample of more than 10,500 twins was used to explore causal associations between music practice and IQ as well as underlying genetic and environmental influences. As expected, phenotypic associations were moderate (*r *= 0.11 and* r *= 0.10 for males and females, respectively). However, the relationship disappeared when controlling for genetic and shared environmental influences using the co-twin control method, indicating that a highly practiced twin did not have higher IQ than the untrained co-twin. In line with that finding, the relationship between practice and IQ was mostly due to shared genetic influences. Findings strongly suggest that associations between music practice and IQ in the general population are non-causal in nature. The implications of the present findings for research on plasticity, modularity, and transfer are discussed.*

Research highlights

- The present study confirms the existence of significant associations between musical practice and intelligence (often interpreted as far transfer) in a large cohort of more than 10,000 twins.
- When controlling for genetic and shared environmental factors the association between practice and cognitive ability disappeared – a trained twin does not score higher on the IQ test than the untrained co-twin – suggesting no causal influence of practice on IQ.
- Genetic modelling showed that the associations between practice and IQ were largely due to shared genetic influences (genetic pleiotropy) with individuals predisposed to possessing higher IQ also being more likely to persist in practising and learning to master an instrument.
- Our findings show that associations between training and cognitive ability on a phenotypic level do not necessarily reflect far transfer, but rather suggest pre-existing differences with shared genes (and potentially shared environment) influencing practice and IQ.

Introduction

Associations between active music engagement and cognitive performance have repeatedly been reported in the literature. Such associations have been shown for domain-specific abilities such as enhanced auditory skills

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(Strait & Kraus, 2014) as well as for a wide variety of non-musical cognitive abilities (for a detailed review see Schellenberg & Weiss, 2013), such as language (Tierney, Krizman, Skoe, Johnston & Kraus, 2013), memory, visuospatial abilities, processing speed, school performance and general intelligence (Jentzsch, Mkrtchian & Kansal, 2014; Moreno, Bialystok, Barac, Schellenberg, Cepeda *et al*., 2011; Schellenberg, 2001, 2004, 2006; Schellenberg & Weiss, 2013). These relationships are of relevance to several topical aspects of cognitive science, such as plasticity (Munte, Altenmuller & Jancke, 2002), modularity (Peretz, 2012), and transfer (Hannon & Trainor, 2007).

The associations on the population level are commonly interpreted as reflecting causal effects of music practice on general cognitive capacities, implying that music practice has far transfer effects. Indeed, the idea of far transfer of music training has received substantial interest in popular media and the scientific community (e.g. Bialystok & De Pape, 2009; Chan, Ho & Cheung, 1998; Ho, Cheung & Chan, 2003; Jentzsch *et al*., 2014) with many positive effects being attributed to musical engagement, especially in early life but also throughout life and into old age. However, evidence for transfer effects of musical practice is largely based on correlational, cross-sectional or quasi-experimental (not controlling for self-selection) studies precluding causal inferences. The limited number of randomized controlled music intervention studies have small samples and show mixed results (for a recent review see Mehr, Schachner, Katz & Spelke, 2013). Only one randomized controlled trial reported a significantly greater increase in general intelligence in two music intervention groups (keyboard and singing) compared to two control groups (drama lessons or no intervention; Schellenberg, 2004). However, the effect size of music training was much smaller compared to associations observed at the population level (e.g. Schellenberg, 2011; Schellenberg & Mankarious, 2012). Another study reported a significant increase in general intelligence after two years of piano training, but not after one or three (Costa-Giomi, 1999). Other studies reported improvements in listening, language-related abilities, or in intelligence-related sub-tests, but not in general cognitive ability (e.g. Bilhartz, Bruhn & Olson, 1999; Chobert, Francois, Velay & Besson, 2014; Francois, Chobert, Besson & Schon, 2013; Moreno *et al*., 2011; Moreno, Marques, Santos, Santos, Castro *et al*., 2009) and finally Mehr *et al*. (2013) reported no effects of music interventions in two randomized trials (note that the amount of music training in the latter study was very limited though with only 4.5 hours in total). In summary, while the prevailing idea is thus that musical training increases general cognitive abilities ('music makes you smarter') the empirical evidence is rather unclear.

An alternative explanation for the associations described above is that pre-existing differences or other underlying factors influence both practice behavior and general intelligence (Corrigall, Schellenberg & Misura, 2013; Schellenberg & Weiss, 2013) resulting in cognitively high functioning individuals also being more likely to engage in music practice. These influences may even be time-lagged, which could account for associations found in prospective studies. Individual genetic variation could be such an underlying factor, with genetic factors influencing general intelligence (IQ) also influencing music practice, explaining the associations often interpreted as far transfer effects of music practice. While there is clear evidence that IQ is highly heritable (Plomin & Spinath, 2004), we were the first to recently show that individual differences in music practice are also partly under genetic influence (40–70%; Mosing, Madison, Pedersen, Kuja-Halkola & Ullén, 2014).

Aims and hypotheses

The present study is the first using a genetically informative sample to explore the relationship between music practice and IQ, allowing us to directly address the question raised above. Specifically, the aims of the present study were: (1) to estimate genetic influences on the covariation between music practice and IQ and (2) to explore the directionality of this relationship. Using a large cohort of twins we can test two predictions based on the causal hypothesis that music practice increases IQ.

First, in genetically identical (MZ) twin pairs differing in their amount of music practice, the more practiced twin would be expected to have a higher IQ score than the less practiced twin (Figure 1a). This means that in MZ pairs the within-twin pair difference in music practice (twin 1 minus twin 2) would be positively associated with the within-pair difference in IQ. Hence, we would expect the association between practice and IQ to still be significant once all genetic (and shared environmental) influences are controlled for.

Second, genetic and environmental influences on music practice (the predictor variable) will also influence IQ (the outcome variable) according to the causal hypothesis (De Moor, Boomsma, Stubbe, Willemsen & de Geus, 2008). This was explored by testing the significance of genetic and environmental influences underlying the association between music practice and IQ (Figure 1b). For a more detailed description of the two hypotheses see the Method section.

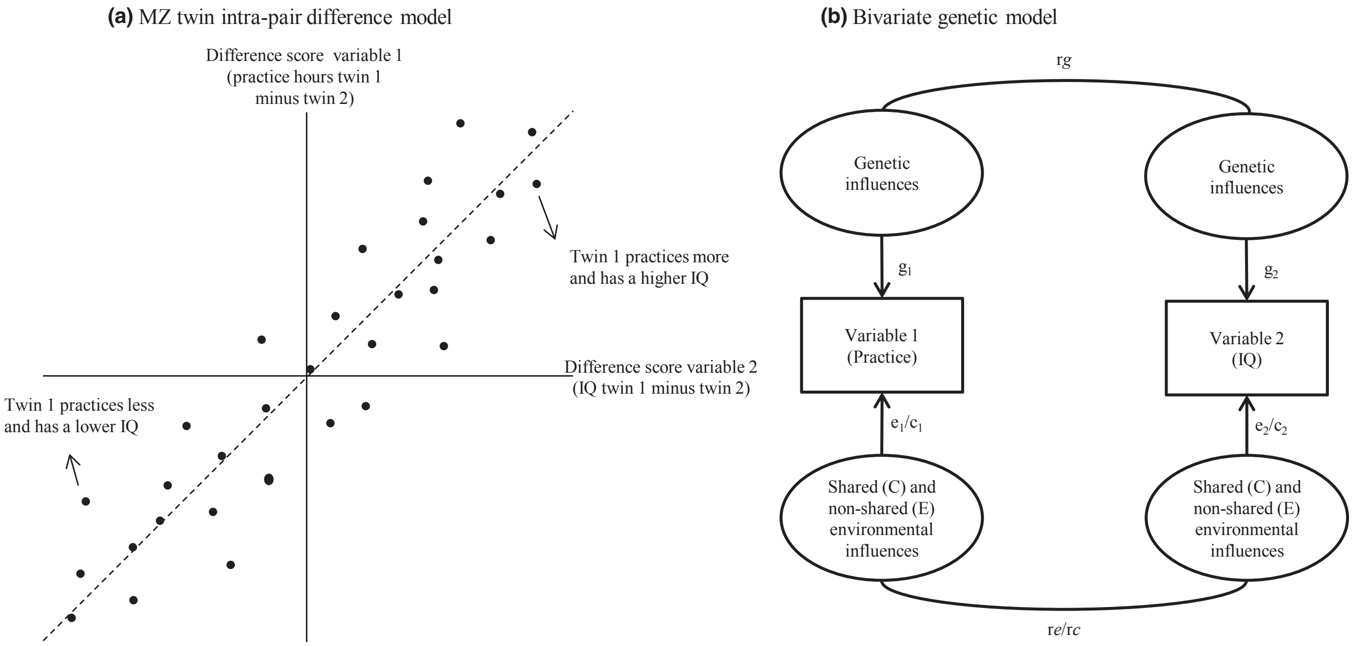

Figure 1 *Graphic representation of the two models used to test the causal hypotheses. (a) The causal hypothesis predicts that in genetically identical twins, the twin scoring higher on music practice would also score higher on IQ than his/her co-twin. (b) Given a causal relationship between the variables, significant genetic and environmental correlations would be expected. e = environmental factor loadings; g = genetic factor loadings; MZ = identical twins; r_c = shared environmental correlation; r_e = non-shared environmental correlation; r_g = genetic correlation.*

Material and methods

Participants

Data were collected as part of a web survey sent out to the STAGE cohort which is part of the Swedish Twin Registry (STR; Lichtenstein, De Faire, Floderus, Svartengren, Svedberg *et al*., 2002; Lichtenstein, Sullivan, Cnattingius, Gatz, Johansson *et al*., 2006). For a detailed description of the survey or the STAGE cohort see Lichtenstein *et al*. (2006) and Mosing *et al*. (2014). Zygosity determination was based on questions about intra-pair resemblance. This method has been confirmed in 27% of the twins in the STR using genotyping and showed an accuracy of more than 98% (Lichtenstein *et al*., 2002; Lichtenstein *et al*., 2006). All participants gave informed consent and the study was approved by the Regional Ethics Review Board in Stockholm (Dnr 2011/570-31/5, 2012/1107/32). The final sample consisted of 10,537 participants with a score for at least one of the two studied traits, and comprised 2568 full twin pairs (1210 MZ and 1358 dizygotic (DZ) twin pairs) and 5401 single twins without the co-twin participating. Participant age ranged between 27 and 54 years (mean 40.7, *SD* 7.7). Single twins were included as they contribute to the estimation of means, variances, and covariance effects.

Measures

Music practice

After indicating whether they ever had played a musical instrument (including singing), participants who responded positively were asked to specify how many hours per week they practiced during four age intervals (age 0–5, 6–11, 12–17, and 18 until the present). A sum score was calculated to get an estimate of the total hours practiced during their life-time, with non-players receiving a score of zero. Reliability for self-reported estimates of practice has been shown to range between 0.6 and 0.9 (Bilalić, McLeod & Gobet, 2007; de Bruin, Smits, Rikers & Schmidt, 2008; Ericsson, Krampe & Tesch-Römer, 1993; Tuffiash, Roring & Ericsson, 2007). Music training was kurtosed ($p < .01$) and positively skewed ($p < .01$) with many participants having no or little practice. Therefore, we also log-transformed the raw practice score and excluded all non-players (individuals who scored zero) to derive a more normally distributed score and repeated all univariate and bivariate analyses.

Although enhancing normality, the transformation (and exclusion of zeroes) did not result in a normal distribution – the Shapiro-Wilk test remained significant ($p < .01$). However, based on the central limit theorem, in big samples the sampling distribution will be close to normal regardless of the data distribution and, hence, the assumption of normality is not easily violated if the sample is large (e.g. Field, 2009). Further, maximum likelihood methods show robustness to violations of the assumption of multivariate normality (Kaplan, 1990). Nevertheless, to be sure that our genetic modelling results were not influenced by skewness of the predictor variable, we also repeated the univariate and bivariate analyses with a dichotomized practice score, comparing individuals who indicated that they practised versus those who did not practise an instrument (or sing). For the bivariate analyses with the dichotomized practice score IQ was also dichotomized (< 100 versus ≥ 100). For further details on the hours of practice (phenotypic and genetic analyses) see Mosing *et al.* (2014).

Wiener Matrizen-Test (WMT)

Psychometric intelligence (IQ) was measured with the WMT (Formann & Piswanger, 1979), a visual matrix test similar in construction to Raven's standard progressive matrices (SPM). Reliability of the WMT has been shown to be relatively high (Cronbach's alpha = 0.81) and WMT scores correlate highly with Raven's SPM ($r = 0.92$) (Formann & Piswanger, 1979). The test consists of 24 multiple choice items. The total score is a sum score with correctly answered items scored as one and incorrect or missing items scored as zero. Participants were given 25 minutes to complete the test, as specified in the manual (Formann & Piswanger, 1979).

Statistical analyses and genetic modelling

The co-twin control design and the classical twin design make use of the fact that MZ twins share all their genes, while DZ twins on average share only 50% of their segregating genes. This means that MZ twins resemble each other much more than DZ twins on a trait under strong genetic influence. Cumulative effects of genes acting in an additive manner are referred to as additive (A) genetic influences. Further, the two members of a twin pair (whether MZ or DZ) share aspects of their environment, such as experiences shared due to their common rearing – these shared influences (C) make the twins more similar to each other. And finally, non-shared environmental factors (E) comprise all aspects of the physical and social environment experienced differentially within twin pairs, making them different from each other (including stochastic biological effects, idiosyncratic experiences, as well as measurement error).

Co-twin control design

The co-twin control design draws its explanatory power from the fact that analyses within MZ twin pairs control not only for all shared environmental influences (C) but also for all genetic influences. So if an association were truly causal (e.g. music practice leads to increased cognitive ability) and is not mediated by genetic or familial effects, it would be assumed that this association is evident not only on the population level, but also within MZ twins, i.e. the more practiced twin has a higher IQ score than the less practiced twin on average (1st prediction, Figure 1a). For a comprehensive discussion of the co-twin control design see McGue, Osler and Christensen (2010). In the MZ twin intra-pair difference model, the difference in practice hours between the MZ twins (twin 1 minus twin 2) was calculated and regressed on the difference score of IQ (twin 1 minus twin 2) for the full MZ sample ($N_{\text{pairs}} = 880$). Further, to address the potential that only large doses of practice affect IQ, the MZ analyses were repeated including only pairs with a practice difference of more than 500 ($N_{\text{pairs}} = 492$) and 1000 hours ($N_{\text{pairs}} = 355$), respectively. Finally, to also address the potential existence of a ceiling affect, i.e. a small dose of practice is sufficient to boost IQ, only MZ pairs were selected with one twin playing while the other one never played ($N_{\text{pairs}} = 127$) and a paired-samples *t*-test was conducted to explore whether the practising twins had a higher IQ score on average than their non-practicing co-twin.

The classical twin design

The genetic and environmental architecture of the practice–IQ association was analysed using the classical twin design. As mentioned above, MZ and DZ twins differ in their level of genetic similarity. This knowledge can be used to partition the variance within and covariance between traits into that due to A, C and E influences. A bivariate ACE Cholesky decomposition was fitted using maximum-likelihood modelling in the flexible matrix algebra programs Mx (Neale, Boker, Xie & Maes, 2006; Neale & Maes, 2004) and OpenMX (Boker, Neale, Maes, Wilde, Spiegel *et al.*, 2012; Boker, Neale, Maes, Wilde, Spiegel *et al.*, 2011). For further information on the classical twin design see Posthuma, Beem, de Geus, van Baal, von Hjelmborg *et al.* (2003) and for examples of utilizing the combined method of co-twin control and classical twin modelling to address causality see De Moor *et al*. (2008) or Bartels, de Moor, van der Aa, Boomsma and de Geus (2012). To estimate genetic (A) and environmental (C and E) influences underlying the association between music practice and IQ we tested the significance of A, C and E correlations (prediction 2). If an association is truly causal we would expect that all significant (ACE) influences on the predictor variable (i.e. music practice) would also significantly contribute to the association between the two traits (i.e. music practice and IQ). Further, if we expect that music practice as an intervention results in cognitive transfer, we would expect to see a significant and strong non-shared environmental (E) correlation, which would also be reflected in the co-twin control analyses, with a significant association between practice and IQ even when all A and C influences have been controlled for. Practice hours and WMT scores were converted to z-scores for all genetic analyses.

Results

Descriptive statistics for the different IQ and practice scores are shown in Table 1. First, we tested the effects of age, sex and zygosity on the means and variances of each of the traits ($\alpha = 0.01$). Females were more likely to play an instrument (80% of women as opposed to 62% of men). In those individuals who played an instrument, there was a significant sex difference in hours practiced ($t(7769) = 4.68$, $p < .001$) with men playing more hours on average ($M = 3862.42$, $SE = 72.46$) than females ($M = 3270.86$, $SE = 52.86$), although the effect size ($r = 0.05$) was very small. Sex also had a significant effect on IQ ($t(8479) = 10.97$, $p < .001$), with men scoring slightly higher ($M = 13.51$, $SE = 0.09$) than females ($M = 12.25$, $SE = 0.07$). Further, age showed a significant mean effect on practice hours ($\beta = 0.13$, $t(10758) = 13.85$, $p < .001$), and IQ ($\beta = -.93$, $t(8479) = -16.71$, $p < .001$) with more hours of practice and lower IQ with increased age. Therefore, sex and age were included as covariates in the twin models. Further, means could be equated across zygosity groups (but not across sexes) for practice and IQ and, while variances could similarly be equated for IQ, the variances differed for music practice between MZ and DZ pairs in both sexes (both $p < .01$). The mean difference scores for practice and IQ were higher in DZ compared to MZ twins, suggesting that MZ twins resemble each other more on those traits than DZ twins, which indicates genetic influences. For further details on the hours of practice (phenotypic and genetic analyses) see Mosing *et al*. (2014).

Although music practice showed a significant positive association with IQ ($r = 0.11$; CI: 0.08–0.13 for males and $r = 0.10$; CI: 0.07–0.12 for females), regression of the intra-pair difference score of musical practice on the difference scores of IQ was non-significant in the full MZ sample ($\beta = 0.00$, $t(879) = -0.16$, $p = .88$), or in the subsamples with more than 500 ($\beta = 0.00$, $t(491) = -0.19$, $p = .85$) or 1000 hours practice difference ($\beta = 0.00$, $t(354) = -0.24$, $p = .81$). Similarly, results of the paired samples t-test comparing the IQ of practicing with their never-practiced co-twins was non-significant ($t(126) = -0.40$, $p = .69$).

Twin correlations (Table 2) and heritability estimates (Table 3) suggested sex differences in genetic and environmental influences on music practice (Mosing *et al*., 2014). Therefore, a bivariate common sex limitation model was fitted, allowing the ACE estimates to differ quantitatively between the sexes.

Bivariate modelling results testing the significance of correlations between music practice and IQ are shown in Table 4. ACE influences on the correlations between

Table 1 *Means (standard deviations) for hours of music practice (untransformed with zeroes and transformed without zeroes) and difference scores for MZ and DZ twins*

	Females				Males			
	Mean (*SD*)	Min	Max	*N*	Mean (*SD*)	Min	Max	*N*
Music practice	2599.6 (3562.6)	0	27040	6203	2298.2 (3534.1)	0	23920	4557
Log music practice* (excluding zeroes)	3.3 (0.5)	1.7	4.4	4898	3.3 (0.5)	1.7	4.4	2827
IQ	12.3 (5.1)	0	24	4908	13.5 (5.4)	0	24	3573
	MZ (males and females combined)				DZ (males and females combined)			
Practice Diff. Score#	1643.7 (2404.8)	0	20228	1207	2490.6 (3095.6)	0	20696	1356
IQ Diff. Score#	3.6 (3.0)	0	17	884	4.8 (3.8)	0	21	916

*base 10 log transformation of the practice score with an added constant; #Note that the difference score presented here was derived by subtracting the score of the lower scoring twin from the score of the higher scoring twin in order to derive a meaningful mean difference score. For the analyses, the difference scores were calculated as 'twin1 minus twin2' which results in a mean of zero and a normal distribution.

Table 2 *Twin correlations for each zygosity for music practice and IQ corrected for sex and age*

Zygosity	Music Practice	Log Practice[a] (excluding zeroes)	Practice dichotomized	IQ
MZ female	0.59 (0.55; 0.63)	0.60 (0.55; 0.65)	0.88 (0.82; 0.92)	0.58 (0.53; 0.63)
MZ male	0.69 (0.65; 0.73)	0.66 (0.59; 0.72)	0.83 (0.75; 0.89)	0.59 (0.52; 0.65)
DZ female	0.44 (0.36; 0.51)	0.48 (0.39; 0.55)	0.50 (0.33; 0.64)	0.35 (0.25; 0.44)
DZ male	0.44 (0.34; 0.52)	0.42 (0.27; 0.54)	0.69 (0.56; 0.80)	0.38 (0.25; 0.48)
DZ opposite-sex	0.36 (0.29; 0.42)	0.28 (0.19; 0.37)	0.49 (0.37; 0.59)	0.27 (0.18; 0.35)

Note: MZ = Monozygotic; DZ = Dizygotic. Twin correlations for music practice in this sample have been reported previously (Mosing *et al.*, 2014). [a]base 10 log transformed music practice score.

Table 3 *ACE estimates with 95% confidence intervals based on univariate general sex limitation modelling corrected for age*

	Music practice[a]	Log practice[#a] (excluding zeroes)	Practice dichotomized	IQ
$\mathbf{A}_{\mathbf{males}}$	0.69 (0.56; 0.75)	0.63 (0.52; 0.70)	0.26 (0.01; 0.55)	0.59 (0.24; 0.65)
$\mathbf{C}_{\mathbf{males}}$	0.04 (0.00; 0.15)	0.02 (0.00; 0.10)	0.56 (0.29; 0.78)	0.00 (0.00; 0.32)
$\mathbf{E}_{\mathbf{males}}$	0.28 (0.24; 0.31)	0.35 (0.29; 0.42)	0.18 (0.12; 0.26)	0.41 (0.35; 0.47)
$\mathbf{A}_{\mathbf{females}}$	0.41 (0.26; 0.56)	0.29 (0.12; 0.47)	0.75 (0.59; 0.87)	0.43 (0.23; 0.63)
$\mathbf{C}_{\mathbf{females}}$	0.21 (0.05; 0.35)	0.33 (0.16; 0.48)	0.12 (0.02; 0.27)	0.16 (0.00; 0.33)
$\mathbf{E}_{\mathbf{females}}$	0.38 (0.37; 0.42)	0.38 (0.34; 0.43)	0.12 (0.08; 0.18)	0.41 (0.37; 0.47)

Note: A = additive genetic influences; C = shared environmental influences, E = non-shared environmental influences. Heritability estimates for music practice in this sample have been reported previously (Mosing *et al.*, 2014). [a]male and female estimates could not be equated without significant deterioration of model fit. [#]base 10 log transformation of the practice score.

Table 4 *Bivariate sex limitation model fitting results for musical practice and IQ corrected for age and sex testing the significance of the ACE correlations*

Model	AIC	−2LL	Δ−2LL	Δ *df*	*p*-value
1. Fully saturated common sex limitation	13537.08	50645.08			
2. Common sex limitation*	13515.90	50715.90	24.36	16	0.08
3. Equate male/ female influences on IQ and r_{ACE}[a]	13509.41	50721.41	5.51	6	0.48
$r_c = 0$[b]	13508.87	50725.92	1.46	1	0.23
$r_e = 0$[b]	13507.46	50722.87	0.05	1	0.83
$r_a = 0$[b]	13511.92	50721.46	4.51	1	<0.05

Note: −2LL = minus twice the log-likelihood of the data; Δ = difference between current and full model; AIC = Akaike information criterion; *df* = degrees of freedom; r_a = additive genetic correlation; r_c = common/shared environmental correlation; r_e = non-shared environmental correlation. [a]compared to model 2. [b]compared to model 3. *Fit indices such as Tucker-Lewis Index (TLI), Normed Fix Index (NFI) and Comparative Fit Index (CFI) were between 0.98 and 1.00.

music practice and IQ could be equated for males and females without significant deterioration of model fit (as indicated by a non-significant *p*-value). Only the genetic correlation was significantly different from zero at 0.19, explaining 85–90% of the phenotypic correlation. Contrary to our second prediction, although music practice was significantly influenced by environment, the environmental correlations were not significantly contributing to the associations between the variables, with R_E = 0.02 and R_C = 0.19 explaining only 2–3% and 7–12% of the phenotypic correlation, respectively. Finally, when repeating the bivariate analyses with the transformed or the dichotomized practice score (see Tables 1–3 for univariate comparison), the results remained the same with R_A explaining most of the correlation between the variables while R_E remained non-significant (additional bivariate results not shown). However, while the bivariate analyses with the log-transformed score (excluding zeroes) closely resembled the results of the analyses with raw scores, the bivariate analyses with the dichotomized scores suggested some shared environmental influences in addition to the genetic influences on the covariation. Given that all bivariate analyses showed an absence of E-contribution to the correlation between practice and IQ, we can be confident that the conclusions drawn from the twin modelling results are correct.

Discussion

The present study is the first to test causal effects of music practice on intelligence using a large genetically informative sample. In line with previous literature, we found a significant positive association of music practice with IQ. Several cross-sectional studies have reported correlations between music practice and measures of general cognitive ability of similar magnitude, as reviewed by Schellenberg and Weiss (2013). Two predictions of the causal hypothesis stating that music practice increases IQ (far transfer) were tested. First, in genetically identical twin pairs, the twin who trains more would also perform better on the intelligence test. Although intra-pair differences in practice ranged up to 20,228 hours, this was not the case – once we controlled for genetic influences, the association between music practice and IQ disappeared. Even when different MZ sub-samples with more extreme practice differences between the pairs (> 500/1000 hours) or only MZ pairs discordant for playing (player vs. never played) were included, no significant effects were seen, suggesting that the findings were not due to potential floor or ceiling effects of practice, i.e. high or very low doses of practice are needed/sufficient to affect IQ.

The second prediction was that all influences on the predictor variable would also influence the outcome variable, using genetic modelling. Although music practice was significantly influenced by additive genetic and environmental influences, the association between the variables was mostly explained by shared genetic influences, with non-shared environmental correlations being close to zero and non-significant. In combination, our findings suggest a non-causal relationship between practice and IQ largely due to genetic pleiotropy. In line with these results, a recent cross-sectional study by Corrigall *et al.* (2013) suggested that some personality traits may influence not only practice habits but also cognitive outcomes. Numerous studies have reported significant genetic influences on personality (Johnson, Vernon & Feiler, 2008) and it appears likely that some of the genetic influences mediating the relationship in our data may be shared with specific personality traits.

Contrary to popular belief, voluntary music practice in the general population may not have any causal influence on intelligence. Indeed, the existence of far cognitive transfer in general is a controversial issue in differential psychology (e.g. Barnett & Ceci, 2002). Although in some areas cognitive transfer has been demonstrated more unambiguously, this typically involved designs where certain principles of problem solving, such as logical or mathematical procedures, are trained in one situation and then successfully applied to a different problem in a different context (Barnett & Ceci, 2002). Music practice does not involve the acquisition of such generally applicable techniques for problem solving. Accordingly, musical transfer effects have commonly been suggested to rely rather on improvement in the function of general cognitive mechanisms, such as working memory, attention and other aspects of executive functions (Bergman Nutley, Darki & Klingberg, 2014; Schellenberg & Weiss, 2013). Notably, however, the extent to which training of such cognitive functions generalizes beyond the trained tasks is also highly controversial, with recent meta-analyses finding little evidence for far transfer (Melby-Lervag & Hulme, 2013; Rapport, Orban, Kofler & Friedman, 2013).

Certainly some forms of imposed and monitored musical training in intervention studies may have different cognitive effects from the voluntary practice studied here. While voluntary practice may be largely genetically influenced, imposed training in a randomized design is by definition more environmentally driven. Voluntary practice may potentially be less structured and cognitively demanding than an imposed regime of maximally efficient training. The relatively small cognitive transfer effects of musical training reported in one of the randomized controlled trials (e.g. Schellenberg, 2004) could reflect such differences between voluntary and imposed musical training. However, as mentioned previously, the evidence for musical transfer from music intervention studies overall is not convincing (Mehr *et al.*, 2013) and, as shown here, the associations on the population level between voluntary practice and IQ are not attributable to cognitive transfer. If indeed a robust cognitive transfer effect of musical practice could be established, a next question would be how long it remains after termination of the intervention programme. In line with the present findings, one would predict that those who continue to practise after a musical intervention may be those who showed higher music skills and intelligence to begin with.

Without doubt musical practice is necessary for the acquisition of a range of different highly specific skills and knowledge required for musical performance, as shown by many cross-sectional and longitudinal studies. Furthermore, some cross-sectional (Bengtsson, Nagy, Forsman, Forssberg, Skare *et al.*, 2005; Gaser & Schlaug, 2003) and longitudinal (Bergman Nutley *et al.*, 2014; Hyde, Lerch, Norton, Forgeard, Winner *et al.*, 2009) imaging studies have suggested that musical training, as well as other forms of long-term deliberate practice, induce plastic changes in involved brain regions. Such effects of music practice on the brain may predominantly reflect the development of specific music-related skills, rather than domain general skills such as cognitive capacity. This is in line with our recent findings showing that voluntary music practice may also not have a causal effect on auditory music discrimination abilities (Mosing *et al.*, 2014). Our study emphasizes that cross-sectional and even longitudinal findings of differences between musicians and non-musicians need to be interpreted with caution and may be genetically mediated or due to other pre-existing differences rather than due to causal effects of music practice.

Results must be interpreted considering the limitations of the present study. The sample included adult Swedish twins and results may differ for other age groups, ethnicities and measurements. Further, reverse or reciprocal causality or combinations of common genetic factors and causal effects of music training cannot be ruled out. While these can be studied using a direction of causation model (Duffy & Martin, 1994; Heath, Kessler, Neale, Hewitt, Eaves *et al.*, 1993), this requires the heritability estimate of the predictor variable to differ significantly from the heritability of the outcome variable, which was not the case here. Lastly, our data do not allow for conclusions about potential transfer effects on more specific areas of cognition as only general cognitive ability was measured here.

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