



## Examining the association between music lessons and intelligence

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Although links between music training and cognitive abilities are relatively well-established, unresolved issues include the generality of the association, the direction of causation, and whether the association is mediated by executive function. Musically trained and untrained 9- to 12-year olds were compared on a measure of IQ and five measures of executive function. IQ and executive function were correlated. The musically trained group had higher IQs than their untrained counterparts and the advantage extended across the IQ subtests. The association between music training and executive function was negligible. These results provide no support for the hypothesis that the association between music training and IQ is mediated by executive function. When considered jointly with the available literature, the findings suggest that children with higher IQs are more likely than their lower-IQ counterparts to take music lessons, and to perform well on a variety of tests of cognitive ability except for those measuring executive function.

The goal of the present investigation was to further our understanding of the association between music lessons and intelligence. Although links between music training and cognitive functioning are relatively well established (for reviews see Schellenberg, 2005, 2006a), the nature of the association remains unclear in several respects (Schellenberg & Peretz, 2008). One outstanding issue involves whether such associations are general or limited to specific subsets of cognitive ability, such as verbal abilities, spatial abilities, or mathematical abilities. Another unresolved matter concerns the direction of causation. Do music lessons cause increases in cognitive abilities, or are high-functioning children more likely than other children to take music lessons? A third unanswered question asks whether the association is direct or mediated by another mechanism (or mechanisms) that may be influenced by music lessons, and, in turn, influence intelligence. When considered in the context of the available literature, the data reported here provide evidence relevant to all three issues.

As one might expect, taking music lessons is associated positively with performance on a wide variety of listening tasks, musical or otherwise. For example, compared to untrained children, musically trained children are better at identifying whether a

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sequence of chords ends in a manner typical of Western music (i.e., on the tonic; Corrigan & Trainor, 2009). In adulthood, music training is associated positively with identifying a familiar melody played at an unusually fast or slow tempo (Andrews, Dowling, Bartlett, & Halpern, 1998), and with detecting small mistunings in familiar melodies (Schellenberg & Moreno, 2010). Musically trained adults also perform better than untrained adults on auditory imagery tasks (Aleman, Nieuwenstein, Böcker, & de Haan, 2000), and such advantages extend to lower-level tasks such as auditory processing speed and frequency discrimination (Schellenberg & Moreno, 2010). In fact, musically trained adults exhibit relatively low levels of informational masking in auditory psychophysical tasks, which suggests that they are, in general, more analytic listeners than their untrained counterparts (Oxenham, Fligor, Mason, & Kidd, 2003). Although it seems reasonable to infer that music training *causes* listening abilities to improve, results from these quasi-experiments (i.e., without random assignment) cannot rule out the possibility that individuals with naturally good listening skills are more likely than other individuals to take music lessons.

More provocative findings reveal associations between music lessons and domains that are tangentially related to music, such as language. Although language and music are both systems of auditory communication (Patel, 2008), the form and function of the two systems are obviously different. Nonetheless, musically trained participants outperform their untrained counterparts on tests that require participants to remember prose (Jakobsob, Cuddy, & Kilgour, 2003; Kilgour, Jakobson, & Cuddy, 2000) or lists of words (Brandler & Rammsayer, 2003; Chan, Ho, & Cheung, 1998; Franklin *et al.*, 2008; Ho, Cheung, & Chan, 2003; Jakobson, Lewycky, Kilgour, & Stoesz, 2008). Music training is also associated positively with reading ability (Douglas & Willatts, 1994; Gardiner, Fox, Knowles, & Jeffrey, 1996; Moreno *et al.*, 2009), vocabulary (Forgeard, Winner, Norton, & Schlaug, 2008; Piro & Ortiz, 2009), sequencing verbal information (Piro & Ortiz, 2009), detecting pitch violations in spoken language (Magne, Schön, & Besson, 2006; Marques, Moreno, Castro, & Besson, 2007; Moreno *et al.*, 2009; Schön, Magne, & Besson, 2004), and decoding emotions conveyed by prosody in speech (Thompson, Schellenberg, & Husain, 2004; but see Trimmer & Cuddy, 2008).

Associations with music training extend beyond language to spatial (Bilhartz, Bruhn, & Olson, 2000; Brochard, Dufour, & Després, 2004; Gromko & Poorman, 1998; Hetland, 2000; Patston, Corballis, Hogg, & Tippett, 2006; Patston, Hogg, & Tippett, 2007; Rauscher, 2002; Rauscher *et al.*, 1997; Sluming, Brooks, Howard, Downes, & Roberts, 2007; Stoesz, Jakobson, Kilgour, & Lewycky, 2007; Zafranas, 2004), mathematical (Bahr & Christensen, 2000; Cheek & Smith, 1999; Gardiner *et al.*, 1996; Graziano, Peterson, & Shaw, 1999; Neufeld, 1986; Vaughn, 2000), and nonverbal (Forgeard *et al.*, 2008; Thompson *et al.*, 2004; Trimmer & Cuddy, 2008) abilities. Musically trained individuals also outperform untrained individuals on tests of short-term (Huntsinger & Jose, 1991; Tierney, Bergeson, & Pisoni, 2008), working (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Franklin *et al.*, 2008; Lee, Lu, & Ko, 2007), and visual (Jakobson *et al.*, 2008) memory; on simple reaction-time tasks (Hughes & Franz, 2007); and on tests of visual-motor integration (Costa-Giomi, 2005; Orsmond & Miller, 1999) and tactile acuity (Ragert, Schmidt, Altenmüller, & Dinse, 2004).

In sum, when the available literature is considered as a whole, it is clear that associations between music training and cognitive abilities are extremely general, extending across a wide variety of tasks. Nevertheless, many authors propose that associations with music training are specific to certain sub-domains of cognitive function. For example, the presumed 'special' association with language is explained as a consequence of

enhanced auditory temporal processing for musically trained individuals (Gaab *et al.*, 2005; Jakobsob *et al.*, 2003; Tallal & Gaab, 2006). Others make claims of a specific link between music training and some particular ability when they fail to find an association between training and a different ability (e.g., Tierney *et al.*, 2008), or when a different cognitive ability is held constant in the analyses (e.g., Jakobson *et al.*, 2008; Stoesz *et al.*, 2007). Failing to reject the null hypothesis can never be interpreted unequivocally, however, particularly when it is likely that a larger sample and increased power would lead to statistical significance (Schellenberg, 2008). Moreover, convincing claims for a *specific* association between cognitive performance and music training require that the association remains evident when a reliable and valid measure of general intelligence, or full-scale IQ (FSIQ), is held constant (Schellenberg, 2009).

Indeed, the vast bulk of the available literature can be explained simply: High-functioning children are more likely than other children to take music lessons, and to perform well on virtually any test they take. In one study (Schellenberg, 2006b), standardized tests of intelligence were administered to approximately 150 children and 150 adults. Both the Wechsler Intelligence Scale for Children - Third Edition (WISC-III; Wechsler, 1991) and the Wechsler Adult Intelligence Scale - Third Edition (WAIS-III; Wechsler, 1997) comprise multiple subtests that measure different aspects of cognitive abilities, including measures of verbal, spatial, and nonverbal abilities, as well as tests of working memory and processing speed. Participants in both samples varied widely in terms of amount of music training received outside of school. Among the children, cognitive performance was associated positively with months of music lessons even after holding constant parents' education, family income, and duration of involvement in non-musical out-of-school activities. In line with the generalist view, such associations were strongest for the aggregate measures (FSIQ and the principal component extracted from the 12 subtests). Moreover, no association between music lessons and an individual index or subtest was particularly strong, and none was evident when general intelligence was held constant.

Schellenberg's (2006b) data also showed that music training was associated positively with the children's performance in school (see also Wetter, Koerner, & Schwaninger, 2009), whether it was measured by school grades or a standardized test of academic achievement. As with the IQ subtests, there was no evidence of a special link between music lessons and any particular school subject. Interestingly, the association between music lessons and scholastic abilities remained evident after controlling for general intelligence. In other words, children who take music lessons for relatively long durations of time tend to be particularly good students, even after controlling for individual differences in IQ.

Results from the sample of adults revealed weaker but still significant associations (Schellenberg, 2006b). Duration of playing music regularly in childhood predicted IQ in adulthood, even when parents' education and family income were held constant, and the association was stronger for general intelligence than for individual index scores or subtests. Music training was also associated with average grade in high school.

Findings of positive associations between duration of music training and intelligence imply that professional musicians should be geniuses, which is patently untrue. Indeed, when 'real musicians' are compared to non-musicians, the associations break down. For example, when students studying music at a university level are compared with students from other disciplines (e.g., psychology, law, business, physics), scores on tests of intelligence are inconsistent (Helmbold, Rammsayer, & Altenmüller, 2005) or favour the non-music students (Brandler & Rammsayer, 2003). When young adults who have

studied music for at least half of their lives are compared with their counterparts with no music lessons, the two groups do not differ in general intelligence (Bialystok & DePape, 2009). Similarly, when participants with an average of 11 years of music lessons are compared to those with no music lessons, there is no difference in general intelligence (Schellenberg & Moreno, 2010). In short, cognitive advantages are evident for those who take music lessons in *addition* to everything else, but not for those who study music *instead* of something else.

With some exceptions, all of the above data are consistent with the hypothesis that high-functioning children are more likely than other children to take music lessons, but not necessarily to become 'real musicians'. In the relatively few studies that assigned children to an experimental (music) intervention, positive findings tend to be equivocal for various reasons. For example, small samples of children were trained in ways that differed from typical music lessons (Douglas & Willatts, 1994; Gardiner *et al.*, 1996; Graziano *et al.*, 1999; Gromko & Poorman, 1998; Moreno *et al.*, 2009), assignment of individuals to the intervention and control conditions was not random (Bilhartz *et al.*, 2000; Gardiner *et al.*, 1996; Graziano *et al.*, 1999; Rauscher *et al.*, 1997), or the sample suffered from high levels of attrition (Rauscher *et al.*, 1997; Thompson *et al.*, 2004). An additional problem concerns the control conditions, which involved no additional lessons of any kind (Bilhartz *et al.*, 2000; Gardiner *et al.*, 1996; Gromko & Poorman, 1998) or activities that were not comparable to music lessons (Douglas & Willatts, 1994, discussion groups; Rauscher *et al.*, 1997, playing with computer software).

Schellenberg (2004) attempted to rectify these problems by conducting a study of 144 6-year olds who were assigned randomly to arts lessons for a year, which necessitated providing the lessons free of charge. There were two music groups and two control groups. Half of the children received music training, either keyboard or vocal lessons, which were taught at the largest and oldest music conservatory in Canada. The other children received drama lessons or no lessons. Across conditions, the lessons were administered to groups of six children at the same location by instructors with similar qualifications. All children were tested on the entire WISC-III before beginning the lessons and starting first grade, and again after the lessons in the summer between first and second grade. Each child also completed standardized tests of academic achievement. There were no differences between the two music groups or between the two control groups on any of the cognitive measures. Increases in FSIQ and academic achievement were higher among the music groups compared to the control groups (e.g., 7.0 vs. 4.3 IQ points, respectively), however, and the results were general, extending across academic disciplines as well as the subtests and indexes of the WISC-III.

To date, Schellenberg's (2004) data represent the only convincing evidence that music lessons *cause* increases in cognitive ability. Nonetheless, although the experimental design allowed for causal inferences, providing music lessons free of charge meant that extraneous factors differed markedly from those of families who pay for lessons. For example, practice was minimal among all groups (10–15 min per week), presumably because parents had no motivation to get their money's worth. One might also ask whether lessons longer than a year would lead to greater benefits. Unfortunately, differential attrition across conditions in an experiment of longer duration would likely play havoc with its internal validity. In Schellenberg's study, six children dropped out of the keyboard lessons before the second testing session, four discontinued the vocal lessons, and two withdrew from the drama lessons (i.e., 8.3% attrition rate in total). Differences in attrition across conditions came close to statistical significance ( $p = .06$ ),

but children who dropped out and those who remained had identical FSIQ scores at the initial test session.

On the one hand, then, there is a mountain of evidence indicating that high-functioning children are more likely than their peers to take music lessons. On the other hand, a single well-designed but artificial experiment provided evidence that one year of music lessons enhances IQ slightly among young children. Because *parsimony* and *random assignment* are both central tenets of the scientific method, must we choose between the two alternative explanations? No, because both perspectives could be correct. The available data indicate that high-functioning children are more likely than other children to take music lessons, which, in turn, exaggerate pre-existing individual differences in cognitive ability.

But if music lessons cause small improvements in cognition or exaggerate existing advantages, how can we explain this association? Intelligence as measured by IQ is remarkably stable across the lifespan (Deary, 2001; Neisser *et al.*, 1996), which makes it unlikely that a single environmental factor could have much of an impact. For example, when individuals are tested on the same IQ test at age 11 and again at age 77, the correlation between the first and second testing sessions is high (i.e., around .7; Deary, Whalley, Lemmon, Crawford, & Starr, 2000). Indeed, a consortium of experts in intelligence concluded that almost half of the variance in IQ among children can be attributed to genetics, and that this percentage increases to about 75% by late adolescence (Neisser *et al.*, 1996). Moreover, shared environmental (between-family) effects on IQ appear to be small or non-existent, which means that the remaining variance (attributable to the environment) stems primarily from idiosyncratic (within-family) differences in experiences that have yet to be identified (Deary, 2001; Harris, 1998).

One possible explanation is that the link between music lessons and general cognitive ability is indirect, mediated by *executive function* (Hannon & Trainor, 2007; Schellenberg & Peretz, 2008). Executive function (also called executive functioning, executive control, cognitive control, or the supervisory attentional system) is a loose construct that allows for 'conscious, goal-directed problem solving', and, when impaired, leads to 'failures to make wise judgments, cognitive inflexibility, poor planning of future actions, and difficulty inhibiting inappropriate responses' (Zelazo, Carlson, & Kesek, 2008, p. 553). As noted by Hannon and Trainor (2007), 'small but widespread effects of musical training on cognitive processing might occur because music lessons train attentional and executive functioning, which benefits almost all cognitive tasks' (p. 470). This mediated link between music lessons and cognition is illustrated in Figure 1. It is a reasonable hypothesis because unlike IQ, executive function is readily modifiable by experience, particularly in childhood (Dowsett & Livesey, 2000; Kloo & Perner, 2003; Rueda, Rothbart, Saccamanno, & Posner, 2005), yet executive function is correlated with IQ (Salthouse, 2005; Salthouse, Atkinson, & Berish, 2003).

To date, empirical evidence of a link between music lessons and executive function is scarce. In a study of individuals 60–85 years of age (Bugos *et al.*, 2007), individual



**Figure 1.** Illustration of the hypothesis that the association between music training and IQ is mediated by executive function.

piano instruction led to significant improvements on a test of processing speed (the Digit Symbol-Coding subtest from the WAIS-III) and on a test of visual attention and task switching (Trail Making Test). The researchers compared the piano and control groups on several additional outcome measures, however, and significant differences for only two of several tests may have stemmed from an inflated probability of Type I error. Moreover, Digit Symbol-Coding test is also a subtest of the Wechsler IQ tests, and the effect for the task-switching measure was not evident when baseline performance (no switching) was taken into account. In a quasi-experimental study of young adults (Bialystok & DePape, 2009), musically trained and untrained individuals did not differ in control conditions of relatively low-level selective-attention tasks (i.e., Simon arrows, auditory Stroop) that are considered to be measures of executive function. When the same tasks required participants to ignore conflicting information, the music group performed better. Again, data from these tasks are typically analyzed by examining differences or proportions between control and conflict conditions separately for each participant, thereby controlling for baseline performance. In short, the available evidence linking music training with executive function is inconclusive.

One of the goals of the present study was to test the hypothesis that the link between music lessons and intelligence is mediated by executive function. Accordingly, musically trained and untrained children were administered an IQ test as well as five different tests of executive function. Evidence supporting the mediation hypothesis requires music training to be associated positively with IQ *and* with executive function, and the association between music lessons and IQ to disappear (or become substantially attenuated) when individual differences in executive function are held constant. A second goal was to provide evidence relevant to the issue of causation. If the mediation hypothesis described above is not supported, and IQ but not executive function is associated with music training, the results would be consistent with the vast bulk of the literature, which implies that high-ability children are more likely than other children to take music lessons. The third and final goal was to examine whether associations between music training and cognitive ability are general or specific. The IQ test provided measures of FSIQ as well as separate scores for sub-areas of cognitive ability. Evidence of associations across the subtests would provide support for the general hypothesis. By contrast, evidence of an association with some subtests but not with others would provide evidence of specificity.

## Method

### Participants

The participants were 106 9- to 12-year olds (54 boys, 52 girls) recruited from the local community, a middle to upper-middle class suburb of Toronto. Approximately half ( $n = 50$ ) were classified as musically trained; the others ( $n = 56$ ) were untrained. Trained 9- and 10-year olds had at least two years of music lessons taken outside of school ( $M = 38$  months,  $SD = 15$ ), whereas trained 11- and 12-year olds had at least 3 years ( $M = 58$  months,  $SD = 17$ ). As in previous research (Schellenberg, 2004, 2006b), the music lessons were not restricted to a single pedagogy. The untrained children had no training in music except for what they learned in school. The gender distribution was balanced and similar in the trained (26 boys, 24 girls) and untrained (28 boys, 28 girls) groups, and the average age was virtually identical between groups (i.e., the difference between

means was less than 4 days). English was the native language for all but three children, who learned English by age 3.

### Measures

IQ was measured with the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), which comprised four subtests administered in a standardized order (Vocabulary, Block Design, Similarities, and Matrix Reasoning). Three subtests (all but Matrix Reasoning) were identical in form and structure to those in the WISC-III but with different items. The Vocabulary subtest required the children to define words (e.g., *What is an animal?*). The Block Design subtest asked them to construct designs from red and white coloured blocks so that the design of the blocks when viewed from above was identical to a target picture. On each trial of the Similarities subtest, children were asked to describe how two words are similar (e.g., *How are a deer and a horse alike?*). The final subtest, Matrix Reasoning, displayed a matrix of coloured drawings on each trial. One section of the matrix was missing, and the child was asked to make a logical decision about how to fill in the missing section with one of five options provided.

The WASI provided a FSIQ score ( $M = 100$ ,  $SD = 15$ ) derived from all four subtests, and well as separate Performance IQ (PIQ; derived from Block Design and Matrix Reasoning) and Verbal IQ (VIQ; derived from Similarities and Vocabulary) scores that measured fluid and crystallized intelligence, respectively. Standardized  $T$  scores ( $M = 50$ ,  $SD = 10$ ) were also provided for each of the four subtests. Each score was based on norms from a large sample of children living in the US, calibrated separately based on age in three-month increments. FSIQ as measured by the WASI is highly correlated with FSIQ as measured by the WISC-III ( $r = .87$ ). The correlation between PIQ as measured by the WASI and the WISC-III is .76; for VIQ it is .82.

Five tests measured different aspects of executive function. The test of attention and working memory was Digit Span (also a subtest of the WISC-III), which comprised forward and backward tasks. The forward task, administered first, required children to recall a list of digits in the order they were presented, whereas the backward task, administered second, required recall in reverse order. For both tasks, the list initially comprised two numbers but it became increasingly longer if children performed correctly on at least one of two trials. When children failed both trials of a given length the task was terminated. Their score was the number of completely correct responses summed across the two tasks, with higher scores indicating better performance.

Verbal fluency can be measured with tests of semantic fluency (e.g., *name all the animals you can in 1 min*) or phonological fluency. Our test of Phonological Fluency had three trials. One asked children to name as many words as they could in 1 min that started with the letter F. Other trials (1 min each) asked children to list words starting with the letter A and the letter S. Thus, each child had three verbal fluency scores: the number of words produced for each letter. Higher scores indicated better performance.

The Sun-Moon Stroop test assessed children's ability to ignore conflicting information. In the *congruent* task (administered first), children were given a sheet of paper with pictures of suns and moons and asked to name as many as they could in 45 s. In the subsequent *incongruent* task (also 45 s), children had to report 'sun' for every moon and 'moon' for every sun. An interference score was calculated separately for each child as a proportion, with the numerator equal to the number of responses in the

inconsistent condition minus the number of responses in the consistent condition, and the denominator equal to the number of responses in the consistent condition. Lower (more negative) scores indicated greater interference, higher scores indicated better performance, and a score of 0 indicated no interference.

The test of problem solving and planning was a computerized version of the Tower of Hanoi. The test comprised three rods and rings that varied in size. The rings were stacked from largest (lowest) to smallest (highest) on the left rod. The child's task was to move the rings one at a time from rod to rod so that the rings were eventually stacked from largest to smallest on the right rod, without ever placing a larger ring on a smaller ring. Participants completed the task first with three rings and then with four rings. Time to completion and number of moves were recorded separately for both versions of the task. Lower scores indicated better performance.

The Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993) was also computer-administered. The WCST is perhaps the most well known measure of executive function (Banich, 2009), or 'the gold standard of executive function tests' (Delis, Kaplan, & Kramer, 2001, p. 2). It measured mental flexibility and rule switching. The test had four cards that remained constant throughout the test. Each card had a different number of geometric shapes (1, 2, 3, or 4), a different colour (red, yellow, green, or blue), and one of four different shapes (circles, squares, triangles, or stars). Children were required to match individual target cards with one of the key cards. They were not told how to match the cards but instead were given feedback after each response as to whether they were right or wrong. The matching rule - based on number, colour, or shape - changed after 10 consecutive correct responses. The total number of errors, the number of perseverative responses, the number of perseverative errors, the number of non-perseverative errors, and the number of conceptual-level responses were all recorded as standard scores ( $M = 100$ ,  $SD = 15$ ), with higher scores indicating better performance.

While the child was being tested, a parent completed a paper-and-pencil questionnaire that asked for detailed information about the child's participation in out-of-school activities including non-musical activities. It also asked for demographic information that could potentially represent confounding variables, such as parents' education, family income, parents' first language, and so on. Parents' education was measured separately for mothers and fathers on an eight-point scale ranging from *some highschool* to *postgraduate degree* and subsequently averaged. Annual family income was measured on a nine-point scale (in \$25,000 increments) ranging from less than \$25,000 to more than \$200,000. Nine parents did not provide information about income.

### **Procedure**

Children were tested individually by assistants who were trained in administering the tests of executive function and the WASI. The five tests of executive function were administered first. The order of four of these (Digit Span, Sun-Moon Stroop, Tower of Hanoi, and WCST) was randomized separately for each child. The three trials of the Phonological Fluency test were administered in between the other four tests, with order randomized separately for each child. Participants were then administered the WASI. The entire test session took approximately 1.5 h. Breaks were provided between tests as required, depending on the individual child.

## Results

### Preliminary analyses

Because three tests of executive function had multiple outcome measures, preliminary analyses examined whether these could be combined into aggregate scores that faithfully represented the original measures. For Phonological Fluency, we added the number of responses across the three trials (i.e., words produced starting with the letter F, A, or S). The total number of responses was correlated highly with the number of responses on each trial,  $r_s \geq .8$ ,  $N = 106$ ,  $p_s < .0001$ . Thus, the total was used as the measure of verbal fluency in the analyses. The four scores on the Tower of Hanoi were submitted to a principal components analysis. A one-factor solution accounted for 59% of the variance in the original four measures, and each original measure was correlated with scores on the principal component,  $r_s \geq .7$ ,  $N = 106$ ,  $p < .0001$ . Accordingly, scores on the principal component were used in the analyses as our measure of problem solving and planning. Similarly, when the five standardized scores on the WCST were submitted to a principal components analyses, a one-factor solution accounted for 89% of the variance in the original measures, and each measure was correlated with scores on the principal component,  $r_s \geq .8$ ,  $N = 106$ ,  $p < .0001$ . Scores on the principal component were used in the analyses as our measure of cognitive flexibility and rule switching.

As in previous research (e.g., Orsmond & Miller, 1999; Schellenberg, 2006b), musically trained and untrained groups differed in terms of demographic background. Compared to their untrained counterparts, musically trained children had more highly educated parents,  $t(104) = 3.04$ ,  $p < .005$ , and they were involved in more non-musical out-of-school activities,  $t(103) = 2.11$ ,  $p < .05$  (data missing from one participant). The average number of parents (i.e., none, one, or both) whose native language was English was larger among untrained than among trained children,  $t(104) = 2.14$ ,  $p < .05$ . Although children with music training came from families with slightly higher incomes than families of untrained children, the difference between groups was not significant,  $p > .1$ . This null result is likely attributable to cultural heterogeneity in the local community (Schellenberg, 2006b).

One-sample *t*-tests confirmed that the present sample of children had IQ scores that were higher than norms (FSIQ, PIQ, and VIQ), whether they were musically trained or untrained,  $p_s < .0005$ . Scores on each of the four subtests for both groups were also higher than norms,  $p_s < .005$ . These results are not surprising because the present sample came primarily from middle and upper-middle class families, and norms are higher among Canadians compared to Americans. As noted, norms for the WASI come from a US sample.

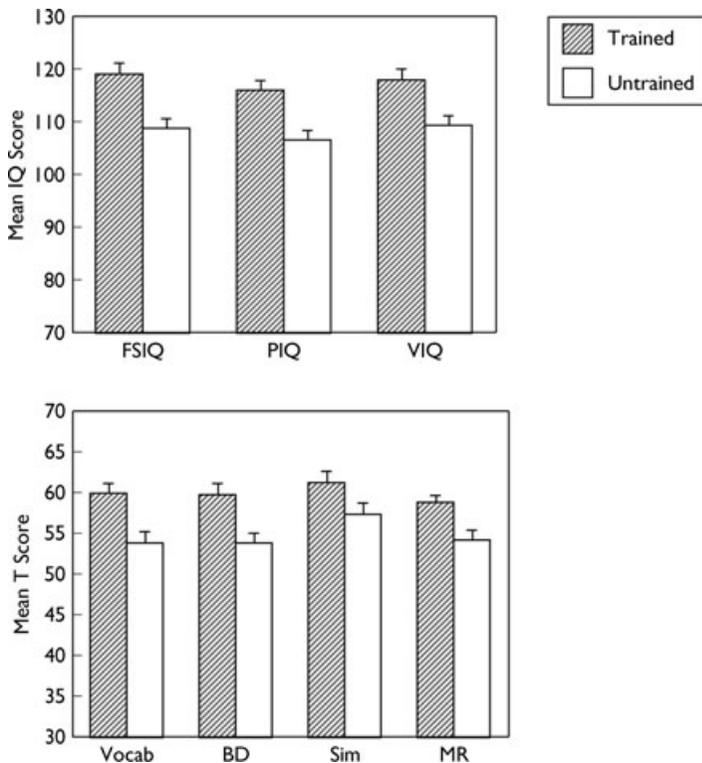
### Principal analyses

Correlations among the WASI IQ scores and subtests are provided in Table 1. Each pairwise association was positive and statistically significant. As shown in Figure 2 (upper), musically trained children had higher FSIQs than their untrained counterparts,  $t(104) = 4.27$ ,  $p < .0001$ . In fact, the difference between groups was substantial (10.3 points, or more than 2/3 of one *SD*) and accounted for 14.9% of the variance in FSIQ. The association between music lessons and FSIQ remained significant when parents' education, parents' first language, family income, and involvement in non-musical out-of-school activities were held constant,  $t(90) = 4.33$ ,  $p < .0001$ , with music training accounting uniquely for 15.2% of the variance in FSIQ.

**Table 1.** Correlations among the measures of intelligence (all  $ps < .0005$ )

	PIQ	VIQ	Vocabulary	Block Design	Similarities	Matrix Reasoning
FSIQ	.86	.88	.79	.73	.80	.74
PIQ		.51	.46	.89	.47	.80
VIQ			.90	.39	.90	.50
Vocabulary				.35	.65	.47
Block design					.36	.46
Similarities						.46

A mixed-design analysis of variance (ANOVA) with PIQ/VIQ as a repeated measure and music training as a between-subjects variable revealed a large main effect of music training,  $F(1, 104) = 17.72, p < .0001$ , but no interaction between training and IQ score,  $F < 1$  (Figure 2, upper). Slightly higher scores for VIQ than for PIQ in the present sample of children fell short of statistical significance,  $p = .07$ . A similar mixed-design ANOVA on the four subtest scores revealed a robust main effect of music training,  $F(1, 104) = 16.70, p < .0001$ , but no interaction between training and subtest,  $F < 1$  (Figure 2, lower). As



**Figure 2.** Scores on the WASI measures of IQ (upper) and the individual subtests (lower) for children with and without music training. Error bars are standard errors. The difference between groups was significant for each comparison. (FSIQ, Full-Scale IQ; PIQ, Performance IQ; VIQ, Verbal IQ; Vocab, Vocabulary; BD, Block Design; Sim, Similarities; MR, Matrix Reasoning).

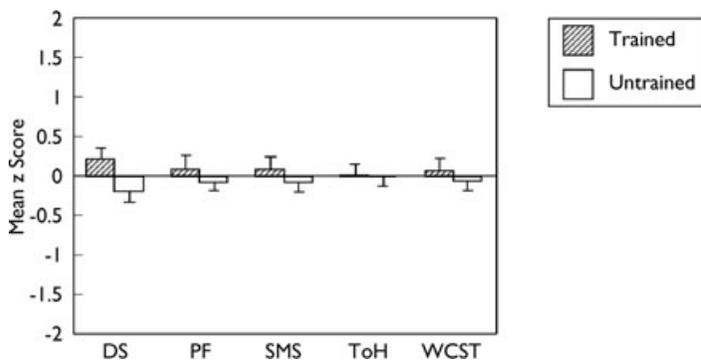
**Table 2.** Correlations among the measures of executive function

	Phonological Fluency	Sun-Moon Stroop	Tower of Hanoi	WCST
Digit Span	.37*	.08	-.21*	.35*
Phonological Fluency		.07	-.29*	.22*
Sun-Moon Stroop			-.15	.24*
Tower of Hanoi				-.24*

\* $p < .05$ .

shown in the figure, a main effect of subtest,  $F(3, 312) = 4.22, p < .01$ , was due to higher performance on Similarities than on the other three subtests,  $ps < .05$ . Regardless, as in previous research (Schellenberg, 2004, 2006b), the association between music training and cognitive functioning was general and not limited to fluid (PIQ) or crystallized (VIQ) intelligence, or to verbal (Vocabulary, Similarities), spatial (Block Design), or nonverbal (Matrix Reasoning) abilities.

Correlations among the five measures of executive function are provided in Table 2. Associations were modest in magnitude (highest  $r = .37$ ), and Sun-Moon Stroop was associated only with WCST. A multivariate ANOVA (MANOVA) compared performance between the musically trained and untrained groups on the five executive-function tasks. The two groups did not differ,  $F(5, 100) = 1.10, p > .3$ . For ease of interpretation, Figure 3 illustrates performance transformed into  $z$  scores ( $M = 0, SD = 1$ ) for each measure of executive function. As in Figure 2, the  $Y$ -axis ranges between two standard deviations above and below the mean, such that absolute differences in the size of the bars are comparable across figures. Additional analyses explored the possibility of group differences separately for each of the five measures. Compared to untrained children, children with music training had higher scores on Digit Span,  $t(104) = 2.22, p < .05$ , with the difference between groups accounting for 4.5% of the variance. The group difference remained evident when parents' education, parents' first language,



**Figure 3.** Normalized scores ( $M = 0, SD = 1$ ) on the measures of executive function illustrated separately for children with and without music training. Higher scores indicate better performance for each measure (the sign for ToH scores was reversed). Error bars are standard errors. The difference between groups was significant only for Digit Span. (DS, Digit Span; PF, Phonological Fluency; SMS, Sun-Moon Stroop; ToH, Tower of Hanoi; WCST, Wisconsin Card Sorting Test).

**Table 3.** Correlations between IQ scores and measures of executive function

	FSIQ	PIQ	VIQ
Digit Span	.37*	.42*	.24*
Phonological fluency	.27*	.25*	.20*
Sun-Moon Stroop	.24*	.26*	.15
Tower of Hanoi	-.38*	-.32*	-.35*
Wisconsin Card Sorting Test	.33*	.32*	.26*

\* $p < .05$ .

family income, and non-musical out-of-school activities were held constant,  $t(90) = 2.29$ ,  $p < .05$ , with group membership accounting uniquely for 5.4% of the variance in Digit Span. There were no differences between the musically trained and untrained groups on Phonological Fluency,  $p > .3$ , Sun-Moon Stroop,  $p > .4$ , Tower of Hanoi,  $p > .9$ , and WCST,  $p > .4$ . In absolute terms, performance was slightly better for the trained group on each measure.

Correlations between IQ (i.e., FSIQ, PIQ, and VIQ) and the five measures of executive function are provided in Table 3. As FSIQ increased, executive-function abilities tended to improve. Associations between executive function and PIQ were similar in magnitude to those between executive function and FSIQ, whereas associations with VIQ were somewhat smaller and less consistent (i.e., not significant for Sun-Moon Stroop). Interestingly, absolute values for the five pairwise associations between FSIQ and executive-function scores were slightly higher than the 10 pairwise associations among the different measures of executive function (see Table 2; Mann-Whitney  $U$  test),  $z = 1.91$ ,  $p = .057$ .

Finally, hierarchical multiple regression was used to model FSIQ as a function of demographic variables (i.e., parents' education, parents' first language, family income, and non-musical out-of-school activities) on the first step, with the five measures of executive function added on the second step, and music lessons (coded as a dummy variable) added on the third step. The initial model was significant,  $F(4, 91) = 3.00$ ,  $p < .05$ , with the demographic variables accounting for 11.7% of the variance in FSIQ. Addition of the executive-function variables on the second step significantly improved the fit of the model,  $F_{inc}(5, 86) = 6.36$ ,  $p < .0001$ , accounting for an additional 23.8% of the variance in FSIQ. The addition of music lessons on the third step improved the fit of the model further,  $F_{inc}(1, 85) = 17.93$ ,  $p < .0001$ , and accounted for an additional 11.2% of the variance in FSIQ.

## Discussion

One goal of the present investigation was to examine whether the association between music training and IQ is mediated by executive function. There was no evidence to support this hypothesis. As in previous research (Schellenberg, 2006b), musically trained children had higher IQs than their untrained counterparts, and this association remained evident when demographic variables (parents' education, parents' first language, family income, and non-musical out-of-school activities) were held constant. Higher IQs were also predictive of better performance on all five measures of executive function. Nonetheless, music training was independent of performance on all tests of executive

function with the exception of Digit Span, which is also a subtest on measures of IQ that are more comprehensive than the WASI (e.g., WISC-III). Finally, the association between music training and IQ remained evident when the executive-function and demographic variables were held constant.

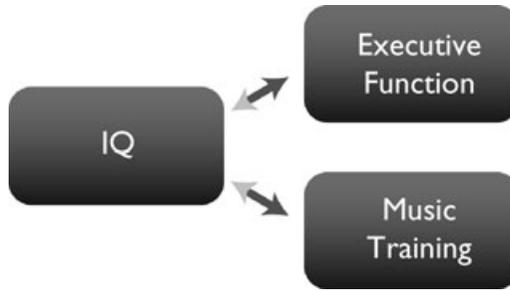
The proposed model outlined in Figure 1 cannot possibly be true if the first arm (music training → executive function) describes an association that does not exist. Could a lack of statistical power be responsible for the null findings? Consider the data for Phonological Fluency, the executive-function measure (besides Digit Span) that came closest to statistical significance. If we assume that the effect size in the sample ( $d = .17$ ) was a reasonable indicator of the effect size in the population, a sample of over 1000 children (534 in both groups) would be required to have an 80% chance of rejecting the null hypothesis (two-tailed test). In other words, if musically trained and untrained children do indeed differ on these tests of executive function, such differences are almost certain to be trivial.

The possibility remains that other aspects of executive function could be associated with music training, and perhaps even mediate the association between music training and IQ. Such mediation would be better described by the skill measured by the specific test (or tests) rather than 'executive function' *per se*. Indeed, the present findings raise doubts about the utility of treating executive function as a viable construct or psychological mechanism distinct from IQ, a critique that has been raised previously by Salthouse (2005) and Salthouse *et al.* (2003). Firstly, the fact that working memory is part of executive function *and* IQ is problematic for supposedly distinct constructs. Even more problematic is the fact that executive function is such a loose construct that it refers to different measures that are correlated only moderately at best. In the present study, correlations among the five measures of executive function were slightly lower than those between executive function and FSIQ.

The present findings are also germane to other contentious issues, specifically those concerning generality and causation. With respect to the question about whether links between music lessons and cognitive abilities are general or limited to specific subsets of cognition, the results provide support for the generalist position. Musically trained children outperformed untrained children across the four subtests and three IQ scores provided by the WASI. These findings replicated those reported earlier when the WISC-III and the WAIS-III rather than the WASI were administered (Schellenberg, 2004, 2006b).

Effects of music lessons on cognitive abilities were not general enough, however, to extend to four tests of executive function. These null findings come as something of a surprise, particularly because the difference in IQ between the musically trained and untrained groups was large, and because IQ was associated with executive function. Nonetheless, we know that IQ and executive function are correlated but not identical (Ardila, Pineda, & Rosselli, 2000). For example, Hebb (1945) reported that patients with frontal-lobe damage can have poor executive function yet normal IQs. Similarly, autism and attention deficit hyperactivity disorder are associated with poor executive function yet affected individuals may perform at normal levels on traditional tests of intelligence (Pennington & Ozonoff, 1996). Musically trained individuals could have a similar profile of relative strengths and weaknesses but with higher levels of ability across domains. Instead of having *deficits* in executive function and *average* intelligence, musically trained individuals appear to be *normal* in executive function and *above-average* in intelligence.

Turning now to the issue of causation, findings of neuroanatomical differences in quasi-experimental studies of musically trained and untrained individuals are typically



**Figure 4.** Illustration of the likely associations between IQ and music lessons, and between IQ and executive function. Compared to darker arrows, lighter arrows imply that the causal direction is likely to be weaker.

interpreted as providing evidence of brain plasticity. In other words, music training is assumed to *cause* changes in brain structure and function. In fact, it has now become standard rhetoric for neuroscientists to claim that the musician's brain constitutes an 'ideal model' of neuroplasticity. For example, one widely cited review article (Münste, Altenüller, & Jäncke, 2002) is entitled 'The musician's brain as a model of neuroplasticity.' Additional claims that musicians constitute an appropriate subject pool for studying learning and neuroplasticity are numerous, even if we consider only articles published since 2008 (e.g., Berkowitz & Ansari, 2010; Habib & Besson, 2009; Herdener *et al.*, 2010; Imfeld, Oeschlin, Meyer, Loenneker, & Jäncke, 2009; Lappe, Herholz, Trainor, & Pantev, 2008; Li *et al.*, 2010; Nikjeh, Lister, & Frish, 2008; Oeschlin, Imfeld, Loenneker, Meyer, & Jäncke, 2010; Schlaug *et al.*, 2009; Shahin, Roberts, Chau, Trainor, & Miller, 2008; Trainor, Shahin, & Roberts, 2009). This view has led to spurious inferences of causation that are too frequent to mention.

Although it is well established that experience and learning affect brain structure and function, it is equally well established that genetics and nature play a role in virtually all aspects of behaviour. While the present study was also quasi-experimental, the results are nonetheless relevant to the issue of causation. Specifically, the substantial difference in IQ between musically trained and untrained children (10 points) is impossible to attribute solely to learning and experience. Indeed, there is no evidence of any environmental factor (other than trauma or severe deprivation) that has such an impact on IQ. For example, effects of relatively dramatic pre-school interventions designed to raise IQ and academic achievement (e.g., 'Head Start' in the US) typically disappear before the end of elementary school (Neisser *et al.*, 1996). More generally, effects on IQ of family upbringing (i.e., environments shared by siblings), which includes sending children to music lessons, are small to non-existent, particularly for measures of general intelligence (Deary, 2001; Harris, 1998).

In other words, genetics must be playing a substantial role in the link between music training and IQ, and genetic differences that cause differences in cognitive ability must be instantiated in the brain. When the present findings are considered in the context of the available literature, the most parsimonious explanation of the observed associations is illustrated in Figure 4, with IQ influencing performance on tests of executive function *and* the likelihood that a child takes music lessons. The figure also acknowledges that music training may cause small increases in IQ (Schellenberg, 2004), as might superior executive-function abilities, such that both links are likely to be somewhat circular. The figure privileges the role of IQ (or general intelligence), in line with the most widely

accepted model of intelligence (Carroll, 1993). If this perspective is correct, music training is better characterized as a model for studying preexisting differences on brain and cognitive development rather than plasticity.

One of the most provocative and interesting findings in the literature is that music training is associated with academic achievement even when IQ is held constant (Schellenberg, 2006b). In other words, children who take music lessons are particularly good students. Besides being above-average in cognitive ability, these children may be unusually motivated to learn, able to concentrate, confident of their own ability, cooperative, interested, and so on. Accordingly, they typically perform well on a wide variety of tests, including tests of intelligence. Exposure to school and additional school-like activities, such as music lessons, may hone these abilities and exaggerate pre-existing advantages. When music training is simply substituted for an equally scholastic ability (e.g., studying psychology), however, there would be no additional advantage.

Pre-existing differences between children who do or do not take music lessons could also include personality factors, especially those that predict academic performance. One likely candidate is Conscientiousness (Bratko, Chamorro-Premuzic, & Saks, 2006; De Fruyt, Van Leeuwen, De Bolle, & De Clercq, 2008; Dollinger & Orf, 1991; Furnham, Chamorro-Premuzic, & McDougall, 2003; Lounsbury, Sundstrom, Loveland, & Gibson, 2003; Paunonen & Ashton, 2001). Other personality traits such as work drive (Lounsbury *et al.*, 2003) and school anxiety, interests, and ability self-perceptions (Spinath, Freudenthaler, & Neubauer, 2010) may also be important, as may specific facets of personality dimensions such as the need for achievement (Paunonen & Ashton, 2001) and intellectual openness (Dollinger & Orf, 1991; Paunonen & Ashton, 2001). As with any real-world question, the situation is likely to be complicated by interactions between personality variables and other variables such as gender (De Fruyt *et al.*, 2008; Spinath *et al.*, 2010; Steinmayr & Spinath, 2008) or age (Laidra, Pullmann, & Allik, 2007).

In sum, the association between music lessons and intelligence is undoubtedly complex. It is important to recognize roles of both nature and nurture in the association, to considering individual differences in personality as well as intelligence, and to broaden the focus to explain what appears to be a special link between music lessons and academic achievement. Careful consideration of what makes children with music lessons particularly good students could help to resolve outstanding issues about associations between music lessons and intelligence.

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