Rhythm Synchronization Performance and Auditory Working Memory in Early and Late-Trained Musicians

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ABSTRACT

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Previous work from our laboratory has shown that adult musicians who began training before the age of 7 (Early-Trained; ET) performed better on a visual-motor tapping task than those who began after the age of 7 (Late-Trained; LT), even when matched on total years of musical training and experience. This supports the idea of a "sensitive" period in childhood development during which musical training results in long-lasting benefits for sensorimotor integration. Two questions were raised regarding the findings from this experiment. Firstly, would this group performance difference be observed using a more familiar, musically relevant task such as auditory rhythms? Secondly, how would cognitive abilities contribute to task performance? To address these questions, ET and LT musicians, matched on years of musical training, hours of current practice and experience, were tested on an auditory rhythm synchronization task. The task consisted of six woodblock rhythms of varying levels of metrical complexity. In addition, participants were tested on cognitive subtests measuring vocabulary, working memory, and pattern recognition. The two groups of musicians differed in their task performance, such that the ET musicians were better at reproducing the temporal structure of the rhythms. There were no group differences on the cognitive measures. However, across both groups, individual task performance correlated with auditory working memory abilities and years of formal training. These results support the idea of a sensitive period during the early years of childhood for developing sensorimotor synchronization abilities.

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Introduction

Many professional musicians have been training since a very young age. As a result, there is a common assumption that superior performance in this domain is associated with training onset at a very young age. However, is this because starting at a young age allows for more years of training or experience? Or, is there something specific about being exposed to this type of experience during the early years of development? Would practicing sensorimotor abilities during the younger years of development have a greater impact on life-long sensorimotor abilities than practice during later years? Musicians provide an ideal population in which to examine the idea of a sensitive period for motor learning during development. Training during this sensitive period of development may be associated with superior sensorimotor abilities involved in playing music and this difference may persist well into adulthood. Behavioural evidence for a sensitive period for musical abilities comes from a phenomenon known as "absolute" or "perfect pitch". Individuals with "perfect pitch" are able to identify a note without a standard and the development of this ability is strongly associated with experience during early childhood (Takeuchi & Hulse, 1993; Trainor, 2005; Zatorre, 2003). Previous research has revealed neuroanatomical differences between Early-Trained (ET) and Late-Trained (LT) musicians (Schlaug et al., 1995). However, group differences in years of musical training were not taken into consideration in these results, therefore it is unclear how differential years of training accounted for these neurological differences. Watanabe and colleagues (2007) observed performance differences on a visual-motor synchronization task between ET and LT musicians, even after controlling for total number of years of musical experience. The goal of the present study was to examine performance differences between ET and LT musicians on an auditory rhythm synchronization task. In addition, different areas of cognitive functioning were assessed to examine their relationship with task performance. This is the first study to compare ET and LT musicians on an auditory rhythm synchronization task and examine the contributing effects of individual cognitive abilities to task performance.

A critical period differs from a sensitive period in that during this critical window of time, sensory input is required for functioning to develop. The effects that follow deprivation of sensory input during such a time cannot be reversed by sensory exposure at a later time (Innocenti, 2007). For example, there are critical periods very early during development of the visual system when stimulation or experience is necessary to develop normal binocular vision (Hooks & Chen, 2007; Wiesel & Hubel, 1965). This period is termed "critical" because binocular vision cannot be regained after this window of time, even if stimulation is restored. What we are suggesting in terms of the development of sensorimotor abilities is not a critical period, but a sensitive period. A sensitive period is a window of time during which experience is particularly influential on development of functioning (Knudsen, 2004). The evidence for sensitive periods in human development comes largely from three domains of research: language and second language acquisition, age effects among deaf children who undergo cochlear implantation and the study of "absolute" or "perfect pitch". Lenneberg (1967) suggested that the effects associated with deprivation of speech or auditory stimulation can be overcome if stimulation is restored early enough during development. As a result, he identified that a "sensitive" period for language development exists and extends up until puberty. This idea was applied to second-language acquisition and evidence suggests that exposure to a second language in earlier years is associated with greater levels of proficiency than exposure during later years of development (Weber-Fox & Neville, 2001). More specifically, Weber-Fox and Neville reported that individuals who received second-language exposure before the age of 7 achieved "native-like" levels of language proficiency, while those who learned between the ages of 7 and 10 and thereafter demonstrated slight deficits such as auditory comprehension of sentence structure. Observations within the language development research have most often been based on unfortunate case studies during which deprivation of language had occurred. Researchers are discovering further support for this sensitive period, however, by observing a positive relationship between age of cochlear implantation and degree of hearing or speech development in congenitally deaf children (Kral, Hartmann, Tillein, Heid, & Klinke, 2001; Sharma, Gilley, Dorman, & Baldwin, 2007; Svirsky, Teoh, & Neuburger, 2004). In fact, sensitive periods have been identified at different stages of the developmental timeline of the auditory system (Moore & Linthicum, 2007). A recent fMRI study revealed differences in network activation between native American Sign Language (ASL) speakers and those who learned ASL at a later time during development (Newman, Bavelier, Corina, Jezzard, & Neville, 2002). These results suggest that a sensitive period during development exists for learning ASL as well as verbal languages. A musical ability known as "absolute pitch" (AP) or "perfect pitch" has also been strongly associated with musical exposure during early years of development (Takeuchi & Hulse, 1993; Trainor, 2005; Zatorre, 2003).

The idea of a sensitive period associated with motor learning was put forth by Watanabe and colleagues (2007) based on their observation that musicians who began training prior to age 7 outperformed musicians who began later on a visual-motor synchronization task. The goal of this study is to further investigate this sensitive period for motor learning by using an auditory rhythm reproduction task. It can be hypothesized that musical training during this sensitive period of development may have an optimal effect on the acquisition of sensorimotor skills involved in playing music and, through extensive practice, may lead to long-term, enhanced sensorimotor abilities. Evidence suggests that the mechanisms involved in sensitive periods are highly influenced by experience or behaviour in addition to biological determinants (Hooks & Chen, 2007; Tomblin, Barker, & Hubbs, 2007).

Many researchers have observed a relationship between musical training and changes in neuroanatomical structure (e.g., Bangert & Schlaug, 2006; Bermudez & Zatorre, 2005; Gaab & Schlaug, 2003; Gaser & Schlaug, 2003; Hutchinson, Lee, Gaab, & Schlaug, 2003; Schlaug et al., 1995; Schlaug, Norton, Overy, & Winner, 2005). Volumetric and functional networks of activation differences between musicians and non-musicians have been observed within the cerebellum, motor regions and auditory regions of the brain (Schlaug, 2001). Bermudez and colleagues (2008) reported cortical thickness and grey matter concentration differences between musicians and non-musicians in frontal and auditory regions. Based on observations of increased auditory and motor cortical representations among musicians as compared to non-musicians, Pantev and colleagues (1998) hypothesized that this observed relationship between sensory input during musical training and sensory cortical organization extends across sensory cortices. Gaser and Schlaug (2003) reported an association between patterns of grey matter distribution and musicianship (i.e., professional, amateur or non-musician) in motor, auditory and visual areas. In strong support of a sensitive period for the motor component of musical skill, Schlaug and colleagues (1995) observed volumetric differences in the anterior corpus callosum between ET and LT musicians. It should be noted, however, that total years of experience were not controlled for, and therefore this group difference may be accounted for by differences in years of experience. A group of researchers have recently put forth strong evidence that the changes in brain structure observed in musicians are a consequence of training-induced neural plasticity (Hyde et al., 2009). Brain structure changes were observed within children after 15 months of music lessons. Furthermore, these changes were associated with increases in performance of auditory and motor tasks. Overall, the evidence suggesting that musical experience influences structural development of the auditory and motor systems is convincing. Given that there is a maturational timeline for neuroanatomical development of both auditory and motor systems and that musical experience is associated with structural differences, there may be a window of time in early childhood development during which the influence of musical training on aspects of structural development of sensorimotor networks is strongest.

Despite the many studies comparing musicians and non-musicians, there are few that focus on the motor aspect associated with musical training (Costa-Giomi, 2005; Schlaug, 2001). Furthermore, few studies have directly examined differences between ET and LT adult musicians while controlling for total years of experience. Watanabe and colleagues (2007) observed sensorimotor performance differences between ET and LT adult musicians using a visually presented sequence. Participants were asked to synchronize their mouse button presses with a temporally complex sequence presented on a computer monitor. The ET group performed significantly better than the LT group in terms of response synchronization, supporting the idea that musical training during a sensitive period in early childhood results in superior sensorimotor synchronization abilities. The observed group difference persisted across 5 days, suggesting that this superior synchronization ability remains even after individual performances reach a plateau.

Two issues were raised as a result of these findings. Firstly, this group difference was observed using a visual-motor task, but this difference in synchronization abilities may be specific to the visual domain or it may generalize across other sensorimotor domains. Therefore, the main purpose for this study was to determine whether the same differences would be observed for an auditory-motor task which is more musically relevant and for which musicians are specifically trained. Secondly, group differences in cognitive abilities may have contributed to the observed difference in task performance. It is possible that the ET musicians had heightened cognitive skills that enabled them to perform the visual-motor synchronization task better than the LT musicians. Therefore, as a secondary goal, cognitive measures were included to determine if and how individual abilities correlate with task performance.

The investigation of the relationship between music and cognitive abilities has been a long-standing area of interest. While a significant amount of research has examined the short-term effects of listening to music on cognitive performance (Thompson, Schellenberg, & Husain, 2001), much remains unknown regarding the relationship between long-term musical training and cognitive abilities. Correlational studies have demonstrated positive associations between music lessons in school-aged children and a variable range of abilities such as verbal-memory, non-verbal reasoning, spatial-temporal reasoning, reading, spelling, speech recognition and mathematics (e.g., Anvari, Trainor, Woodside, & Levy, 2002; Forgeard, Winner, Norton, & Schlaug, 2008; Moreno, Marques, Santos, Santos, Castro, & Besson, 2009; Saffran, 2003; Schellenberg, 2001; Schellenberg, 2004; Schellenberg, 2006; Schlaug, Norton, Overy, & Winner, 2005). Lynn, Wilson and Gault (1989) went so far as to conclude that simple musical tests may be measures of general intelligence. However, these positive associations have not been consistently observed across studies and several issues remain unresolved within the literature. Some of these issues are difficulty with inference of causation due to the nature of correlational designs, differentiating between musicianship, dissociating effects of music lessons from musical aptitude, and the specificity or transfer effects of the abilities associated with musical experience or experience (Schellenberg & Peretz, 2008). Furthermore, few studies have accurately isolated the effects of music lessons by controlling for the influence of other extra-curricular activities, the non-musical contributions provided by music lessons, *a priori* group differences, or socio-economic status. Schellenberg (2004) was one of the first to report a positive association between duration of music lessons in school-aged children and Intelligence Quotient (IQ) scores, while controlling for socio-economic status and effects associated with participation in a non-musical activity. A large group of six-year old children were randomly assigned to piano lessons, voice lessons, drama lessons or no extra-curricular activity for a year. After controlling for socio-economic status, the overall increase in full-scale IQ scores was significantly larger in the music groups than in the drama or control group. Among adults, however, very little research has been conducted examining the long-term effects of musical training on cognitive abilities. Correlational data support an association between years of music lessons and overall IQ scores in an undergraduate population, after controlling for parental education, gender, and family income (Schellenberg, 2006). In particular, the cognitive abilities significantly associated with consistent musical experience were working memory and perceptual organization abilities.

Although the literature supports positive associations between musical training and cognitive abilities, the extent to which these musically trained cognitive abilities may transfer to non-musical tasks is unclear (Schellenberg, 2001). It has been argued that the transfer effects should be considerable, as musical training itself involves such a vast number of abilities (e.g., attention, memory, visual-motor feedback, auditory-motor synchronization, timing, self-discipline, etc.). However, it can also be argued that musically trained cognitive abilities are specific to musical tasks (Schellenberg, 2001). A more recent argument has been made to suggest that music lessons may be associated with enhancements in executive control processes such as attention or memory (Schellenberg & Peretz, 2008). This study provides insight into the range of cognitive abilities within a group of extensively trained adult musicians, and if these abilities are associated with performing an auditory rhythm synchronization task.

The performance differences observed by Watanabe and colleagues (2007) between ET and LT musicians were observed within the visual modality and therefore may be specific to visual-motor response synchronization. The present study was designed to determine if these differences would also be extracted using auditory stimuli. Given that a large component of musical training takes place within the auditory modality, auditory rhythms provide an ideal paradigm to examine performance differences between ET and LT musicians. Due to the high degree of musical training obtained by our participants, the auditory stimuli were selected to cover a wide range of complexity. Essens and Povel (1985; 1995) put forth a model by which musical rhythms can be classified into levels of difficulty based on their metrical structure. Rhythms that can be subdivided into equal temporal components are interpreted as metrical and can be reproduced more easily. Rhythms that do not allow for the superimposition of a repeating temporal structure are interpreted as non-metrical and are designed to be more difficult to reproduce. The three types of rhythms that were used in this experiment met the criteria put forth by Essens and Povel for increasingly complex categories: metrically simple (MS), metrically complex (MC) and non-metric (NM). A similar auditory rhythm paradigm has been previously used during an fMRI study conducted by Chen and colleagues (2008) examining the network of activation during auditory-motor synchronization. This study revealed that performance of the three types of rhythms was better in musicians compared to non-musicians and that the performance measure indicative of asynchrony reflected the predicted association between metrical complexity and difficulty in rhythm synchronization. The main goal of this study is to investigate whether the performance differences between ET and LT musicians observed by Watanabe and colleagues can be seen with a more familiar and more musically relevant rhythm task.

Method

Participants

Twenty-four currently practicing, neurologically healthy musicians between the ages of 18 and 34 (M = 26.4 years old, SD = 4.4) participated in this study. Participants were screened for significant head injuries, history of neurological disease or medication that could affect task performance by completing a Medical Screening Information form (Appendix A). The musical training and experience of each participant was determined through the Musical Experience Questionnaire (MEQ; Appendix B). The MEQ quantifies the amount of instrumental, vocal or dance training an individual has received in their lifetime, at what age this training occurred and the amount of time currently dedicated to practicing music on a weekly basis. All musicians had extensive musical experience (M = 17.5 yrs; SD = 4.4), as evaluated by the MEQ. The sample was selected to form two groups of musicians: Early-Trained (ET; n = 12) and Late-Trained (LT; n = 12). Those who began their musical experience prior to or at the age of 7 were placed in the ET group and those who began after the age of 7 were considered LT. The two groups were individually matched on years of musical experience, years of formal training and hours of current practice, as determined by the MEQ. All participants were recruited via word of mouth, online advertisements on the Concordia University website or flyers posted on the Loyola campus of Concordia University. The Concordia University Human Research Ethics committee approved the study protocol. All participants provided informed consent (Appendix C) and received monetary compensation for their time.

Stimuli

The six woodblock test rhythms were designed based on Essens and Povel's rules of metrical complexity (1985; 1995). Each test rhythm consisted of 11 woodblock sounds and had a total duration of 6 seconds. These rhythms differed in their temporal structure, such that the intervals between musical notes varied, resulting in progressively more complex and less metrically structured rhythms. Three levels of metrical complexity were chosen, and participants were exposed to two rhythms at each level: metrically simple (MS), metrically complex (MC), and non-metrical (NM). An auditory stimulus delivery program was used to counterbalance the rhythms. These rhythms were played through a pair of earphones and participants used a computer mouse to tap out the rhythms.

In addition to the rhythmic stimuli, the experimental protocol included two subtests from the Wechsler Adult Intelligence Scale – III (WAIS; Wechsler, 1997), Digit-Span Task (DS) and Letter-Number Sequencing Task (LN), as well as two subtests from the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), Vocabulary Task (VC) and Matrix Reasoning (MR) Task. The DS requires individuals to recall strings of numbers and the LN requires individuals to recall and mentally manipulate strings of letters and numbers. Both of these subtests tap into working memory abilities. The VC assesses an individual's ability to orally define a subset of words and the MR assesses visual pattern recognition abilities. VC was chosen as a subtest representing verbal abilities. However, it is also the subtest that has the strongest correlation with overall IQ scores.

Procedure

After informed consent was provided, the task was explained to participants. Participants alternated between listening and tapping along while each rhythm played twice in row (Fig. 1). Participants were instructed to use their right index finger and the

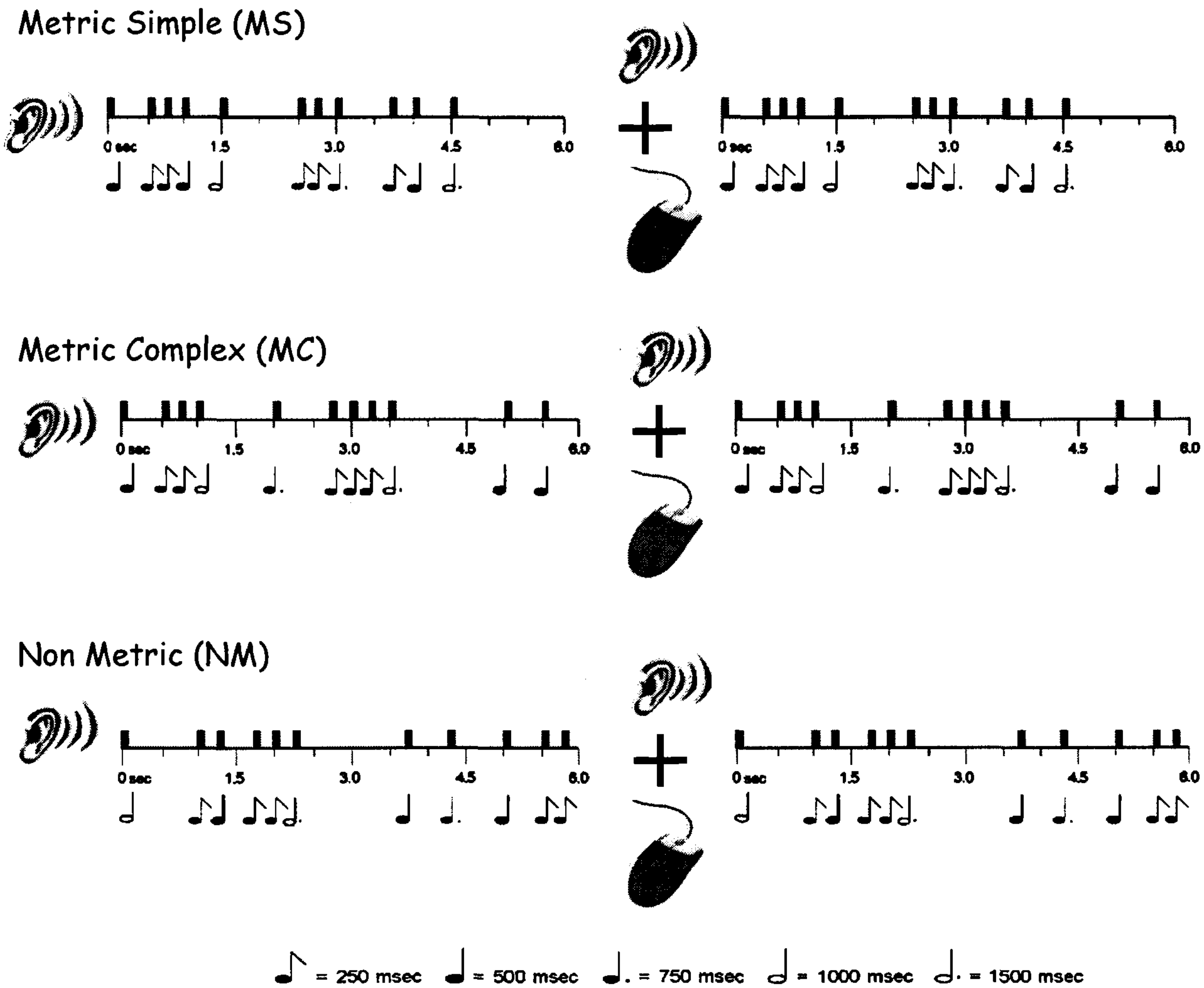

Figure 1. Illustration of the rhythm task. Participants were exposed to six rhythms presented in random order for approximately two 12-minute blocks. Two different rhythms of each rhythmic complexity were used (i.e., 2 MS rhythms, 2 MC rhythms, and 2 NM rhythms). Each trial consisted of a listening component followed by a listening and tapping component.

left button of the computer mouse to tap along with the rhythm as it played during the tapping repetition. Two very basic practice rhythms were used to familiarize participants with the task. A block consisted of the six rhythms repeatedly presented in a counterbalanced fashion for 12 minutes. Each rhythm was performed 6 times in each block. Once participants had completed the first block of the task, they were asked to perform the DS. Participants then performed a second block of the rhythm synchronization task, followed by the VC, the LN and finally, the MR.

Measures

Musical information was quantified for each participant in terms of years of experience, years of formal training and hours of current weekly practice. Individual cognitive abilities were measured using the four chosen cognitive subtests (DS, LN, VC, and MR). Results were scored according to standard procedure, and both raw and scaled scores were included for each cognitive measure. Performance on the rhythm synchronization task was measured using three dependent variables: percent correct (PC), asynchrony (ASYN) and percent inter-tap-interval deviation (ITI). A tap was considered correct if it was made within half of the onset-to-onset interval before or after a woodblock note (Fig. 2). The ASYN measure was defined as the absolute measure of temporal difference between the onset of each woodblock sound and the associated mouse key press. The ITI measure indicates the extent of deviation from reproducing the actual interval between each pair of woodblock sounds. It is calculated as a ratio by dividing the interval between each pair of the participant's taps by the interval between each corresponding pair of the woodblock sounds of the rhythms. This measure provides

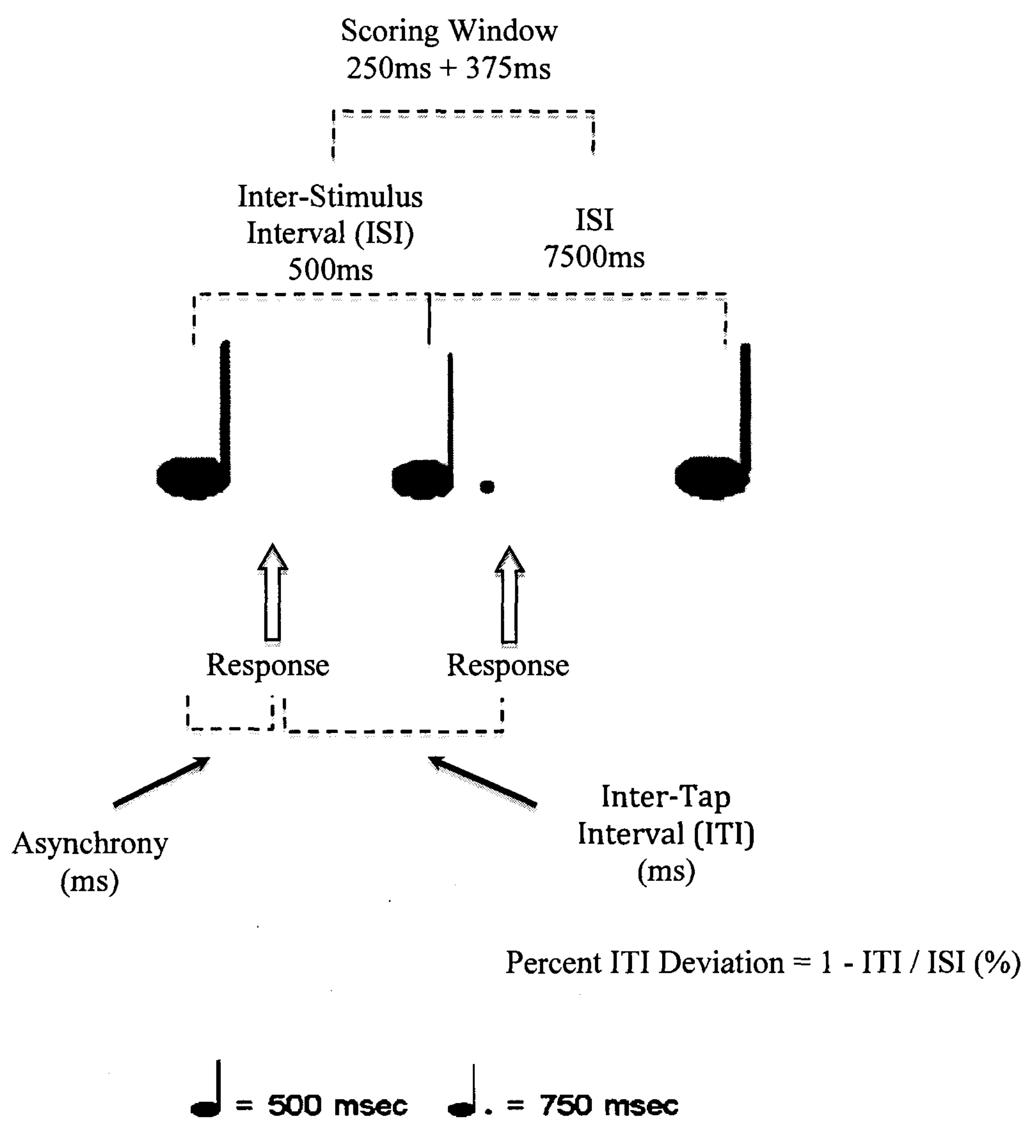

Figure 2. Illustration of the scoring method used to evaluate rhythm task performance. A response was scored correctly if the mouse tap was made within half of the onset-to-onset interval before or after a woodblock note. Asynchrony was measured as the difference between each woodblock note and the participant's response. Percent ITI deviation was calculated as a ratio of the ITI and the ISI.

additional information regarding how well participants are learning the temporal structure of the rhythms.

Data Analysis

To compare rhythm synchronization across groups, a repeated-measures analysis of variance (ANOVA) for each of the dependent variables was conducted, with group as the between-subjects factor and rhythm type as the within-subjects factor. Significant differences across rhythm types for the two groups were analyzed using simple Bonferroni correction for multiple comparisons. Group differences in musical experience, years of formal training, hours of current practice, and cognitive measures were assessed using t-test analyses. The relationship between musical demographics, cognitive measures, age and task performance was examined using Pearson and partial correlation analyses. Raw scores on the cognitive subtests were used in order to examine cognitive abilities, regardless of age.

Results

Group Comparisons of Matching Variables

Comparison analyses between the ET and LT musicians on the matching variables (Table 1) confirmed that the two groups were well matched in terms of years of musical experience, formal training and hours of current practice. Another set of analyses comparing the two groups on their cognitive subtest performance scores (Table 2) demonstrated that the two groups did not differ in their cognitive abilities, as assessed by the VC, MR, DS and LN. As expected, the two groups differed in terms of age of onset ($p < 0.01$).

Behavioural Measures

The repeated-measures ANOVA for PC did not yield a main effect of group, however, a significant main effect of rhythm type ($F(2, 21) = 19.5, p < 0.001$) was observed (Fig. 3). Pair-wise comparisons revealed that performance decreased as metrical complexity increased such that PC was highest for the MS rhythms, second highest for the MC rhythms and lowest for the NM rhythms.

A similar pattern of results was revealed on the behavioural measure ASYN. There was no main effect of group, but a significant main effect of rhythm type ($F(2, 21) = 71.6, p < 0.001$). Pair-wise comparisons revealed that ASYN was lowest on the MS rhythms, second lowest on the MC rhythms and highest on the NM rhythms (Fig. 3).

The repeated-measures ANOVA for ITI showed a significant main effect of group ($F(1, 22) = 6.0, p < 0.05$) such that the ET group reproduced the temporal intervals of the rhythms better than the LT group (Fig. 3). A main effect of rhythm type was observed as

Table 1

Group Demographics of Musical Variables

Group	Age	Age of Onset	Years of Musical Experience	Years of Formal Training	Hours of Current Weekly Practice
Early-Trained	25.0 (±3.8)	5.92 (±1.0)	18.67 (±4.5)	10.00 (±4.2)	19.50 (±10.9)
Late-Trained	27.8 (±4.7)	10.67 (±3.0)	16.42 (±4.3)	7.33 (±4.2)	23.75 (±16.3)
t-Test	*n.s.*	$p < 0.001$	*n.s.*	*n.s.*	*n.s.*

n.s. = not significant
Standard Deviation values are in brackets

Table 2

Group Cognitive Subtest Scores

Group	Vocabulary (Raw)	Vocabulary (Scaled)	Matrix Reasoning (Raw)	Matrix Reasoning (Scaled)	Digit Span (Raw)	Digit Span (Scaled)	Letter-Number Sequencing (Raw)	Letter-Number Sequencing (Scaled)
Early-Trained	63.6 (±5.7)	12.6 (±2.0)	29.8 (±4.3)	12.8 (±2.6)	22.3 (±4.8)	12.8 (±3.5)	13.3 (±2.4)	12.2 (±2.7)
Late-Trained	63.3(±7.0)	12.3 (±2.3)	29.8 (±2.6)	13.4 (±1.7)	19.8 (±4.2)	11.8 (±3.2)	11.6 (±2.7)	10.4 (±2.9)
t-Test	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

n.s. = not significant
Standard Deviation values are in brackets

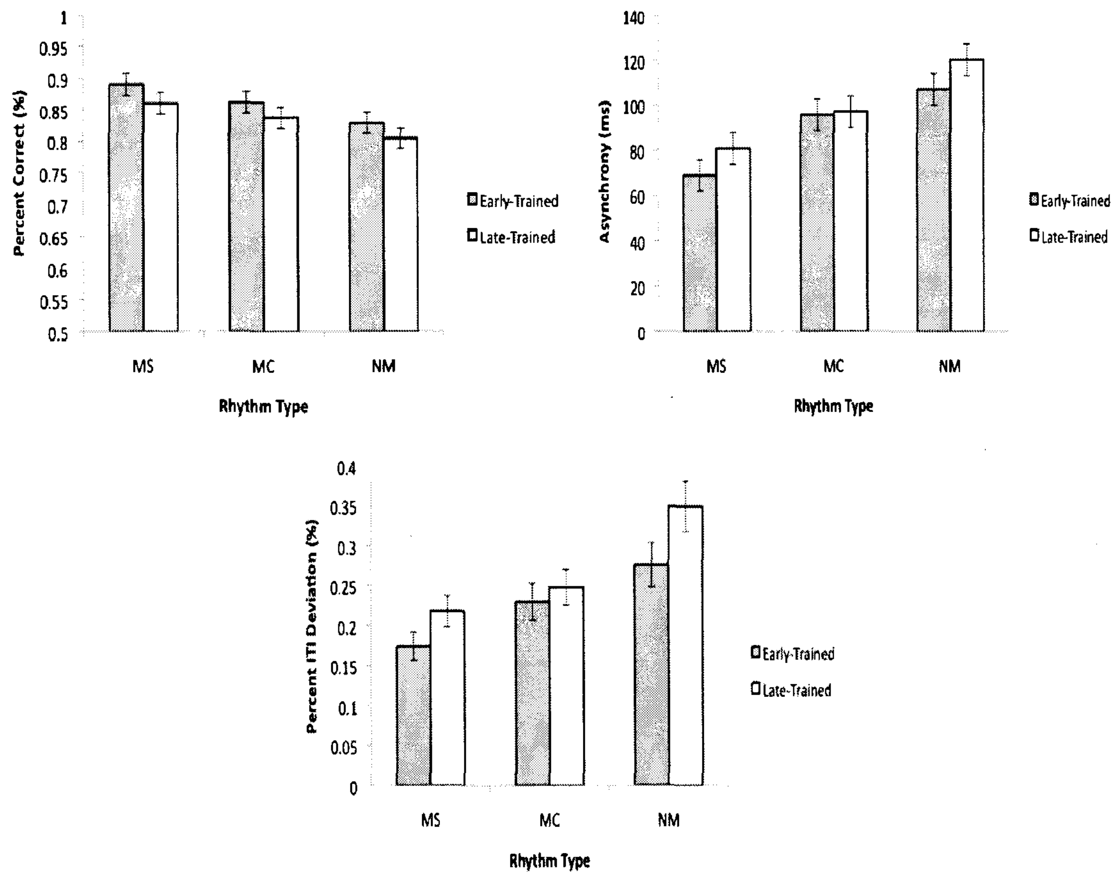

Figure 3. Task performance results as measured by Percent Correct (PC), Asynchrony (ASYN) and percent ITI deviation (ITI). Repeated-measures ANOVA analyses on each performance measure revealed a significant main effect of rhythm type and a significant main effect of group Percent ITI Deviation.

well ($F(2, 21) = 43.6, p < 0.001$), indicating that ITI was the lowest on the MS rhythms, second lowest on the MC rhythms and highest on the NM rhythms.

Correlations

In order to examine the relationship between task performance and cognitive variables, raw scores for PC, ASYN and ITI were correlated with raw scores for VC, MR, DS and LN (Table 3). No significant correlations were found between the behavioural measures and VC or MR scores. However, LN scores were found to be significantly correlated with PC, ASYN and ITI and DS scores were significantly correlated with ASYN and ITI. Figure 4 illustrates the correlational analyses between task performance and the working memory cognitive subtests (DS and LN).

Results of the correlational analyses between the behavioural measures and musical variables, as well as behavioural measures and age variables can be seen in Table 4. A significant correlation between formal training and PC, ASYN and ITI was observed. Neither age variable (age of onset and age) showed a significant relationship with task performance. In order to examine the association between years of formal training, cognitive scores and task performance, correlations were performed between years of formal training and each cognitive measure (Table 5). This set of analyses revealed a significant correlation between years of formal training and both DS and LN, but no significant correlation with VC or MR. In addition, partial correlation analyses between ITI, years of formal training and LN raw scores were conducted in order to examine the independent contributions of formal training and working memory to task performance (Table 6). These results indicated that working memory abilities and years

Table 3
Pearson Correlations of Cognitive Subtest Raw Scores and Behavioural Measures

Behavioural Measure	Vocabulary (Raw)	Matrix Reasoning (Raw)	Digit Span (Raw)	Letter-Number Sequencing (Raw)
Total Percent Correct (PC)	-0.218	0.173	0.256	0.423*
Total Asynchrony (ASYN)	0.088	-0.297	-0.499*	-0.557**
Total Inter-Tap Interval Deviation (ITI)	-0.022	-0.348	-0.549**	-0.563**

Note. * $p < 0.05$, ** $p < 0.01$

Table 4
Pearson Correlations of Musical Experience Variables and Behavioural Measures

Behavioural Measure	Age of Onset	Years of Experience	Years of Formal Training	Hours of Current Weekly Practice
Total Percent Correct (PC)	-0.204	0.114	0.490*	-0.074
Total Asynchrony (ASYN)	0.060	0.003	-0.486*	0.025
Total Inter-Tap Interval Deviation (ITI)	0.190	-0.035	-0.627**	0.134

Note. * $p < 0.05$, ** $p < 0.01$

Table 5
Pearson Correlations of Cognitive Subtest Raw Scores and Years of Formal Training

	Vocabulary (Raw)	Matrix Reasoning (Raw)	Digit Span (Raw)	Letter-Number Sequencing (Raw)
Years of Formal Training	0.152	0.375	0.510*	0.429*

Note. * $p < 0.05$

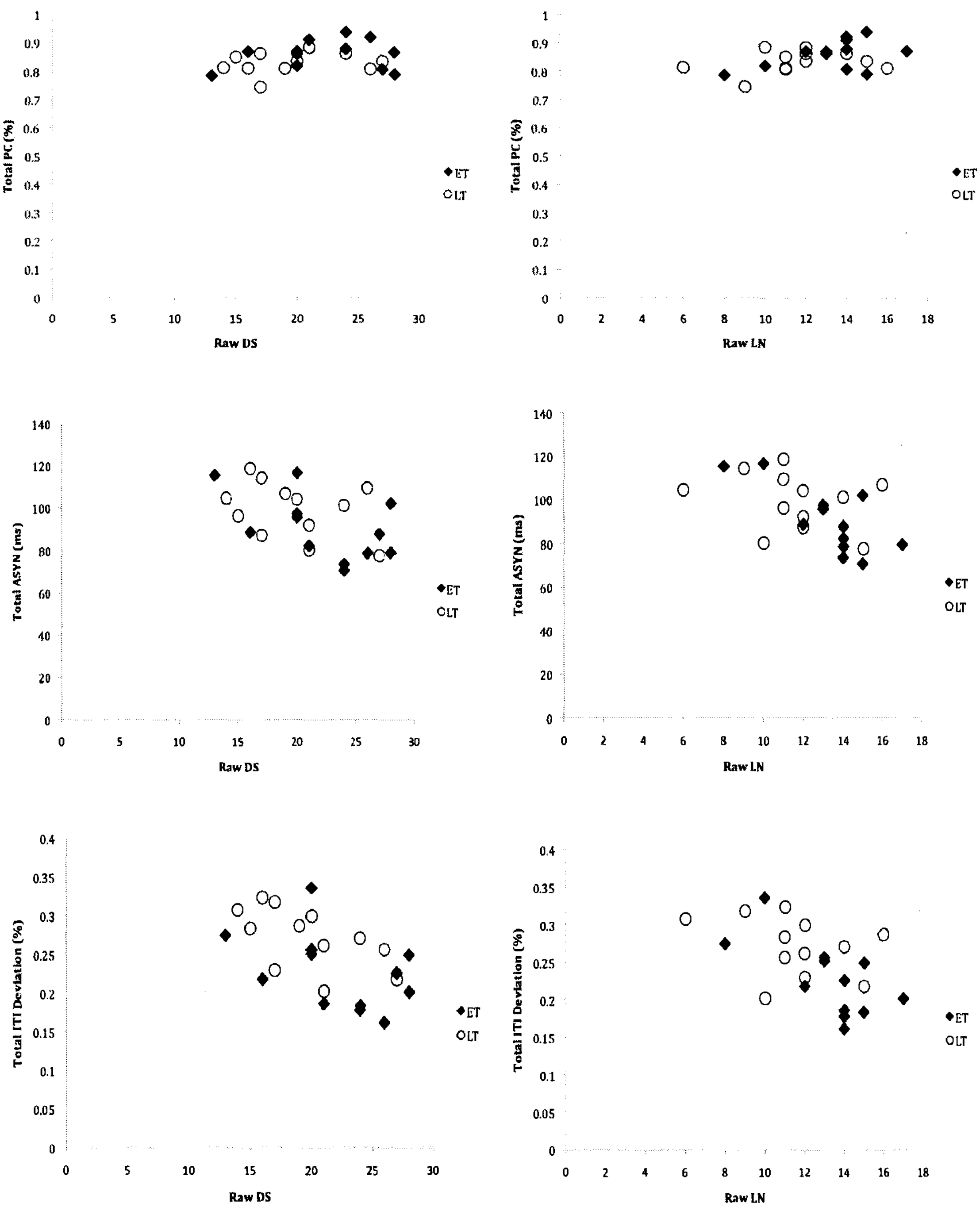

Figure 4. Scatterplots of task performance and each memory subtest. Pearson correlation analyses revealed a significant positive correlation between PC and LN scores (r = 0.423). Significant negative correlations between both ASYN and ITI with DS (r = -0.499; r = -0.549) and LN (r = -0.557; r = -0.563) were also observed.

Table 6

Partial Correlation Analyses Between Task Performance, Years of Formal Training, and Working Memory

Control Variable		Correlation
Letter-Number Sequencing (Raw)	Total ITI Deviation (%)	-0.516*
	Years of Formal Training	
Years of Formal Training	Total ITI Deviation (%)	-0.419*
	Letter-Number Sequencing (Raw)	

Note. * $p < 0.05$

of formal training accounted for independent portions of the variance in task performance.

Discussion

The results from this study indicate that ET musicians have superior rhythm synchronization abilities than LT musicians within the auditory-motor modality. The greatest group performance difference was observed on the percent ITI deviation measure, suggesting that the ET musicians were better able to reproduce the temporal structure of the rhythms than the LT musicians. These group differences cannot be attributed to differences in cognitive abilities, as there were no group differences on these measures. These results support the hypothesis for a sensitive period for motor learning during development associated with long-lasting sensorimotor integration abilities. When performance was examined across all musicians, individual working memory abilities and years of formal training were positively associated with task performance.

Given that the two groups of musicians were matched in terms of musical experience, the enhanced auditory-motor integration ability observed in the ET group cannot be attributed to their extensive years of training, but instead to the developmental window during which their musical experience took place. The performance difference between the ET group and LT group observed in the present study, taken with the results from Watanabe and colleagues (2007), further supports the theory of a sensitive period in development during which musical training results in long-lasting, superior sensorimotor integration abilities across the different sensory modalities. This is consistent with developmental changes in motor performance and structural maturation of fiber pathways supporting sensorimotor functions (Savion-Lemieux, Bailey & Penhune, 2009; Paus et al., 1999). For example, Schlaug and colleagues (1995) observed an increased anterior portion of the corpus callosum among musicians who began before the age of 7 compared with musicians who began afterwards. Thompson and colleagues (2000) put forth a theoretical local growth trajectory of the corpus callosum suggesting that the anterior portion of the corpus callosum precedes the posterior portion in terms of developmental growth. More specifically, Thompson and colleagues (2000) hypothesized that the anterior portion of the corpus callosum demonstrates volumetric growth until approximately age 7. This is supported by a study conducted by Bengtsson and colleagues (2005) that examined white matter differences across different age groups among piano players. Across three age groups (≤ 11; 12-16; ≥ 17), the number of brain regions correlating with practice was largest within the youngest childhood group. Of particular interest was the finding that the two areas within the corpus callosum that correlated with practice in the youngest childhood group were the isthmus (extending into the upper splenium) and the callosal body. The isthmus contains fibres connecting auditory regions and the body of the corpus callosum connects frontal and premotor regions important for movement sequences and bimanual coördination. Bengtsson and colleagues hypothesized that training-induced effects on white matter are strongest when the training takes place during a period when the involved fibre tracts are still maturing. These findings illustrate the potential for a sensitive period in childhood, when motor and sensory regions are still undergoing maturation, during which musical training has an optimal effect on structural development in the involved regions.

These results are congruent with performance differences observed by Watanabe and colleagues (2007) within the visual modality. In their study, the two musician groups did not differ on the first day in terms of asynchrony. It was only on the second day that performance differences were observed between the two groups. These differences persisted across the other days until the fifth and final day of task performance. In the current study, performance differences were revealed on the ITI variable, but group differences did not reach significance for the ASYN measure. One could predict that, given a second day of the task, the two groups would deviate in performance on the ASYN variable as well. Perhaps an important step towards complete rhythm synchronization is the ability to reproduce the global temporal structure of a rhythm. This reasoning is supported by the high degree of correlation between the measures ASYN and ITI ($r = 0.91$).

Given that the two groups did not differ in terms of their cognitive abilities, the superior performance of the ET group cannot be attributed to differences in cognitive ability. While the cognitive abilities of the two groups did not differ at the time of testing, an important question is whether this was true throughout development and at the time of their musical training. The cognitive tasks used in this study are subtests from the WAIS-III or the WASI. Overall IQ scores are thought to be more or less stable across development and, in the absence of significant neurological disruption, demonstrate limited change over normal development. If, however, the ET group had higher IQ scores as children, the LT group would have had to demonstrate an increase in IQ scores during their development, as the two groups do not differ currently. In light of the stability associated with IQ levels across the age span, the difference in task performance observed in these adult musicians is unlikely to be associated with potential group differences in IQ scores at an earlier time during childhood.

Across both groups of musicians, regardless of group, the cognitive measure that contributed to task performance was working memory. These results show that among a homogeneous group of highly trained musicians, vocabulary or pattern recognition abilities were not contributing to task performance, but working memory abilities were. In addition, the amount of formal training of each musician contributed to task performance. This is one of few studies examining the relationship between cognitive abilities, formal training and behavioural measures of musical performance.

The partial correlation analyses indicated that both working memory abilities and total years of formal musical training accounted for independent portions of the variance observed in task performance. Previous findings indicated that musical training during childhood is associated with verbal abilities and non-verbal reasoning (e.g., MR) (Foreguard, Winner, Norton & Schlaug, 2008; Schellenberg, 2004). The current study does not support an association between musical training and verbal or non-verbal reasoning abilities within a group of highly trained adult musicians; however, there was no non-musician group for comparison. Perhaps, it is when comparing musicians versus non-musician that musical training shows an association with verbal and non-verbal reasoning. Furthermore, it is important to distinguish between effects of musical training that are short-term in childhood and those that are long-lasting into adulthood. It may be that music lessons trigger premature development of cognitive abilities, but some of these differences wash out as other children's cognitive abilities develop through other avenues of experience.

An interesting finding was the relationship between years of formal training, memory abilities, and task performance. These results suggest that components of formal music lessons, not general musical experience, are associated with enhanced memory abilities. An important distinction should be made in the literature between effects of formal music lessons and effects of playing music, as alluded to by Schellenberg and Peretz (2008). Many aspects of music lessons are similar to scholastic requirements (e.g., attention, practice, self-discipline, memorization, reading, counting, etc.). Perhaps formal lessons provide a scaffolding instructional approach for all skills involved in playing a musical instrument, including working memory. More specifically, working memory abilities may be more rigorously exercised with a teacher present. Schellenberg and Peretz (2008) suggested that the observed association between overall IQ and music lessons may be accounted for by executive function abilities, such as working memory. Perhaps certain executive functions are trained through formal music lessons, and it is this change in executive function that mediates observed positive associations between musical training and overall IQ scores.

The nature of the sensorimotor performance difference observed in this study and by Watanabe and colleagues (2007) should be explored further with the use of other tasks and brain imaging techniques. For example, one could speculate that performance between these two groups may differ on other motor tasks related to music such as bimanual coordination or any other type of task involving synchronization of movements with an external cue. In order to determine if the observed performance differences are specific to sensorimotor tasks, discrimination tasks or other non-motor tasks should be used in future studies. For example, if performance differences were observed on tasks that require sensorimotor synchronization but not on sensory discrimination tasks, this information would provide further support regarding a sensitive period specifically tied to motor learning. Furthermore, it would be very informative to examine structural differences between the two groups and how these differences correlate with behavioural performance and individual cognitive abilities. Functional magnetic resonance imaging could be used to investigate differences in network activation between groups as well as correlate activation levels with task performance measures. Both adult and longitudinal designs are needed to determine the causality involved in the observed relationship between musical training, structural development, and long-term effects on sensorimotor abilities. At this point in time, it is unclear how structural differences relate to performance or behaviour. More studies correlating structure with behaviour are needed in order to clarify how different components of anatomical structure correlate with different aspects of performance.

In conclusion, the present study provides supporting evidence for a sensitive period associated with motor learning, as demonstrated by performance differences between ET and LT musicians on a rhythm synchronization task. Performance differences cannot be attributed to differences in cognitive ability, as the two groups did not differ on their VC, MR, DS and LN scores. Individual years of formal training and memory subtest scores were also associated with task performance. These results illustrate that partial variance in task performance can be accounted for by the age at which musical experience took place, and additional variance can be accounted for by individual differences in years of formal training, and working memory abilities.

References

Anvari, S., Trainor, L., Woodside, J., & Levy, B. (2002). Relations among musical skills, phonological processing, and early reading ability in preschool children. *Journal of experimental child psychology, 83* (2), 111-30.

Bangert, M., & Schlaug, G. (2006). Specialization of the specialized in features of external human brain morphology. *The European journal of neuroscience, 24* (6), 1832-4.

Bengtsson, S. L., Nagy, Z., Skare, S., Forsman, L., Forssberg, H., & Ullen, F. (2005). Extensive piano practicing has regionally specific effects on white matter development. *Nature Neuroscience, 8* (9), 1148-50.

Bermudez, P., Lerch, J., Evans, A., & Zatorre, R. (2009). Neuroanatomical correlates of musicianship as revealed by cortical thickness and voxel-based morphometry. *Cerebral Cortex, 19,* 1583-96.

Bermudez, P., & Zatorre, R. (2005). Differences in gray matter between musicians and nonmusicians. *Annals of the New York Academy of Sciences, 1060*, 395-9.

Chen, J., Penhune, V., & Zatorre, R. (2008). Moving on time: brain network for auditory-motor synchronization is modulated by rhythm complexity and musical training. *Journal of cognitive neuroscience, 20* (2), 226-39.

Costa-Giomi, E. (2005). Does music instruction improve fine motor abilities? *Annals of the New York Academy of Sciences, 1060*, 262-4.

Essens, P. (1995). Structuring temporal sequences: comparison of models and factors of complexity. *Perception & psychophysics, 57* (4), 519-32.

Essens, P., & Povel, D. (1985). Metrical and nonmetrical representations of temporal patterns. *Perception & psychophysics, 37* (1), 1-7.

Forgeard, M., Winner, E., Norton, A., & Schlaug, G. (2008). Practicing a musical instrument in childhood is associated with enhanced verbal ability and nonverbal reasoning. *PLoS ONE, 3* (10), e3566.

Gaab, N., & Schlaug, G. (2003). Musicians differ from nonmusicians in brain activation despite performance matching. *Annals of the New York Academy of Sciences, 999*, 385-8.

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *The Journal of neuroscience : the official journal of the Society for Neuroscience, 23* (27), 9240-5.

Hooks, B., & Chen, C. (2007). Critical periods in the visual system: changing views for a model of experience-dependent plasticity. *Neuron, 56* (2), 312-26.

Hutchinson, S., Lee, L.-L., Gaab, N., & Schlaug, G. (2003). Cerebellar volume of musicians. *Cerebral cortex, 13* (9), 943-9.

Hyde, K. L., Lerch, J., Norton, A., Foregeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical training shapes structural brain development. *Journal of Neuroscience, 29* (10), *3019-25.*

Innocenti, G. (2007). Subcortical regulation of cortical development: some effects of early, selective deprivations. *Progress in brain research, 164*, 23-37.

Knudsen, E. I. (2004). Sensitive periods in the development of the brain and behaviour. *Journal of Cognitive Neuroscience, 16* (8), 1412-25.

Kral, A., Hartmann, R., Tillein, J., Heid, S., & Klinke, R. (2001). Delayed maturation and sensitive periods in the auditory cortex. *Audiology & Neuro-otology, 6* (6), 346-62.

Lenneberg, E. (1967). *Biological Foundations of Language.* Wiley: New York.

Lynn, R., Wilson, R. G., & Gault, A. (1989). Simple musical tests as measures of Spearman's g. *Personality and Individual Differences, 10,* 25-28.

Moore, J., & Linthicum, F. (2007). The human auditory system: a timeline of development. *International journal of audiology, 46* (9), 460-78.

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: more evidence for brain plasticity. *Cerebral cortex, 19* (3), 712-23.

Newman, A., Bavelier, D., Corina, D., Jezzard, P., & Neville, H. (2002). A critical period for right hemisphere recruitment in American Sign Language processing. *Nature neuroscience, 5* (1), 76-80.

Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L., & Hoke, M. (1998). Increased auditory cortical representation in musicians. *Nature, 392* (6678), 811-4.

Paus, T., Zijdenbos, A., Worsley, K., Collins, D. L., Blumenthal, J., Giedd, J. N., Rapoport, A. L., & Evans, A. C. (1999). Structural maturation of neural pathways in children and adolescents: in vivo study. *Science, 283* (5409), *1908-11.*

Saffran, J. (2003). Musical learning and language development. *Annals of the New York Academy of Sciences, 999*, 397-401.

Savion-Lemieux, T., Bailey, J., & Penhune, V. (2009). Developmental contributions to motor sequence learning. *Experimental Brain Research, 195,* 293-306.

Schellenberg, E. (2001). Music and nonmusical abilities. *Annals of the New York Academy of Sciences, 930*, 355-71.

Schellenberg, E. (2004). Music lessons enhance IQ. *Psychological Science, 15* (8), 511-4.

Schellenberg, E. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology, 98* (2), 457-468.

Schellenberg, E., & Peretz, I. (2008). Music, language and cognition: unresolved issues. *Trends in Cognitive Sciences, 12* (2), 45-6.

Schlaug, G. (2001). The brain of musicians. A model for functional and structural adaptation. *Annals of the New York Academy of Sciences, 930*, 281-99.

Schlaug, G., Jäncke, L., Huang, Y., Staiger, J., & Steinmetz, H. (1995). Increased corpus callosum size in musicians. *Neuropsychologia, 33* (8), 1047-55.

Schlaug, G., Norton, A., Overy, K., & Winner, E. (2005). Effects of music training on the child's brain and cognitive development. *Annals of the New York Academy of Sciences, 1060*, 219-30.

Sharma, A., Gilley, P., Dorman, M., & Baldwin, R. (2007). Deprivation-induced cortical reorganization in children with cochlear implants. *International journal of audiology, 46* (9), 494-9.

Svirsky, M., Teoh, S.-W., & Neuburger, H. (2004). Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. *Audiology & neuro-otology, 9* (4), 224-33.

Takeuchi, A., & Hulse, S. (1993). Absolute pitch. *Psychological bulletin, 113* (2), 345-61.

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, mood, and the Mozart effect. *Psychological Science: A Journal of the American Psychological Association, 12* (3), 248-51.

Tomblin, J., Barker, B., & Hubbs, S. (2007). Developmental constraints on language development in children with cochlear implants. *International journal of audiology, 46* (9), 512-23.

Trainor, L. (2005). Are there critical periods for musical development? *Developmental Psychobiology, 46* (3), 262-78.

Watanabe, D., Savion-Lemieux, T., & Penhune, V. (2007). The effect of early musical training on adult motor performance: evidence for a sensitive period in motor learning. *Experimental Brain Research, 176* (2), 332-40.

Wiesel, T. N., & Hubel, D. N. (1965). Extent of recovery from the effects of visual deprivation in kittens. *Journal of Neurophysiology, 28* (6), 1060-72.

Weber-Fox, C., & Neville, H. J. (2001). Sensitive periods differentiating processing of open- and closed-class words: an ERP study of bilinguals. *Journal of Speech and Language Hearing Research, 44* (6), 1338-53.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale – Third Edition*. San Antonio, TX: Psychological Corporation.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence.* San Antonio, TX: Psychological Corporation.

Zatorre, R. (2003). Absolute pitch: a model for understanding the influence of genes and development on neural and cognitive function. *Nature Neuroscience, 6* (7), 692-5.

Zatorre, R., Chen, J., & Penhune, V. (2007). When the brain plays music: auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience , 8* (7), 547-58.

Appendix A

Medical Screening Information Questionnaire

<u>Medical Screening Information</u>

Given name: ____________________ Family name: _________________________

Participant's ID:

____

Male _____ Female _____

Telephone number(s): ( ) ____

Can we leave a message on answering machine? ___________________

Email address: ____

Date of birth: _________________________ Age: __________________________

Medical Condition

Head injuries:

____

Exclude if the person had a significant head injury and were actually hospitalized or were unconscious for more than 24 hrs.

Medication:

____

Exclude if taking medication for any neurological disease (i.e. Multiple Sclerosis etc.)

Remarks:

____

____

I should tell you that there are other interesting studies being conducted in our department. Would I be able to pass on your name and number to a colleague? The info you have just given me will remain confidential.

☐ YES ☐ NO

Appendix B

Musical Experience Questionnaire (MEQ)

Musical Experience Questionnaire

To be completed by the experimenter(s):

Early or Late trained musician: EARLY LATE
NOTES/COMMENTS:____

To be completed by the participant:

NAME: ______________________________
DATE: ______________________________
Age: _____ **Date of Birth (dd/mm/yyyy):** __________
Gender: M F

1) Do you consider yourself to be a musician? *(please circle)* **Y N**

2) Can you read music? **Y N**
For example: Can you read and play a basic piece of music (e.g. a single-lined melody)?

3) Can you write music? **Y N**
For example: Can you write a single line of melody for example by dictation?

4) What are your musical listening habits?
For example: What types of music do you listen to? Approximately how many hours per day?

5) Have you been involved in any other activities – musical or not – that you think might affect your listening abilities? (e.g. sound design, sound engineering, work in a musical environment, etc.)

6) What kind(s) of musical experience do you have?

Instrumental:	[1] __________	[2] __________	[3] __________
Voice:	[4] __________	[5] __________	[6] __________
Dance:	[7] __________	[8] __________	[9] __________

Which one do you see as most important? [ ]

7) Please provide the details of your musical experience:

No.	Currently Practicing	Start Age	Stop Age	No. Years	Style	Theoretical/ Practical Training	Details (Yrs of lessons, etc)
[ ]	Y☐ N ☐	____	____	____	________	T☐ P☐	______________
[ ]	Y☐ N ☐	____	____	____	________	T☐ P☐	______________
[ ]	Y☐ N ☐	____	____	____	________	T☐ P☐	______________
[ ]	Y☐ N ☐	____	____	____	________	T☐ P☐	______________
[ ]	Y☐ N ☐	____	____	____	________	T☐ P☐	______________

8) How often do you practice? *(please indicate <u>exactly</u> how many hours/wk within each category)*

No.	0-1/wk	2-3/wk	4-5/wk	6+/wk	0-5hrs/wk	6-10hrs/wk	11-15hrs/wk	16+hrs/wk
[ ]	____	____	____	____	____	____	____	____
[ ]	____	____	____	____	____	____	____	____
[ ]	____	____	____	____	____	____	____	____
[ ]	____	____	____	____	____	____	____	____
[ ]	____	____	____	____	____	____	____	____

9) What formal level of musical training did you reach on each? *(if applicable)*

No.	Level (Please specify which training program, i.e. Quebec Conservatory, Royal Conservatory of Music (Toronto), Suzuki, etc.)
[ ]	____
[ ]	____
[ ]	____
[ ]	____
[ ]	____

10) Have you ever (or will you) received a degree/diploma in music or certification from a recognized musical conservatory/program? **Y** **N**

If yes, please specify:

____

11) Do you have perfect pitch *(absolute pitch)*? **Y** **N**

Level of certainty: 1 [low] to 5 [high] _____

For example: Can you name a note without a standard? Can you do so uniquely for your instrument or for other instruments as well?

12) Do you have relative pitch? **Y** **N**
Rank your RP ability: 1 [low] to 5 [high] _____
For example: If you heard two notes on a piano, could you indicate the interval between them (i.e. a third)?

13) Do you have any auditory problems? **Y** **N**
If so, please specify______________________________
____
____
____

14) Do you have any musical problems? **Y** **N**
If so, please specify______________________________
____
____
____

15) Do you have any language or speech impairments (i.e. dyslexia)? **Y** **N**
Do you have any learning disabilities?
If so, please specify: ______________________________
____
____
____

16) Please describe the musical experience of your parents and sibling *(if applicable)*:

Relative	Currently Practicing	Start Age	Stop Age	No. Years	Style	Theoretical/ Practical Training	Details
Mother	Y☐ N ☐	____	____	____	________	T☐ P☐	____________
Father	Y☐ N ☐	____	____	____	________	T☐ P☐	____________
Sibling	Y☐ N ☐	____	____	____	________	T☐ P☐	____________
Sibling	Y☐ N ☐	____	____	____	________	T☐ P☐	____________
Sibling	Y☐ N ☐	____	____	____	________	T☐ P☐	____________

17) Do any members of your immediate family have absolute pitch? Y N
If so, who? _________________________
____
____

18) What is your GPA? ______ out of 4.0 or 4.3 (*please circle)*

19) What level of education have your parents obtained? Mother: _____________ Father: _____________

Appendix C

Consent Form

LABORATORY FOR MOTOR LEARNING AND NEURAL PLASTICITY

CONSENT FORM TO PARTICIPATE IN RESEARCH

Title of project: Musical and cognitive performance in early- and late-trained musicians
Researchers: Dr. Virginia Penhune (PI)
Anne Bailey (Graduate student researcher)
Amanda Daly (Undergraduate researcher)
Laura Fontil (Research Assistant)

This is to state that I agree to participate in a program of research being conducted in the Laboratory for Motor Skill Learning and Neural Plasticity in the Department of Psychology at Concordia University.

A. PURPOSE

The purpose of this study is to advance our knowledge of the contributions of development to learning of motor skills, similar to playing the piano. In the future, this knowledge may also increase our understanding of brain disorders resulting from disease or injury.

B. PROCEDURES

This experiment requires a single testing session of approximately 1 hour. You will be tested on a motor skill task in which you will be asked to reproduce a series of musical rhythms using a single key of the computer mouse. You will also be asked to complete a test of vocabulary, a visual reasoning task and two tests of auditory short-term memory. Finally, you will complete a questionnaire regarding your musical training and experience. You will be compensated $30 for your time and willingness to contribute to this research study.

Advantages and disadvantages: Participation in this study has no personal benefits. On a long term basis, the study may help us gain knowledge about motor learning and development. There are no physical risks associated with participation in this experiment. The only disadvantage of participation is the time you will spend doing the test and traveling to and from the laboratory. The investigator may end the study at any time for purely scientific reasons. In this case, compensation will be made for the part of the study completed.

C. CONDITIONS OF PARTICIPATION

I understand that my participation is entirely voluntary and that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences. I further understand that all records and test results of this study will be kept strictly confidential. No one but the experimenters will have access to any information about me or my performance. In addition, my name will not be used in any report or publication.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

____
Name

____
Signature Date

____
Witness signature Date

For further information about this study either before or after it is completed, please feel free to contact:
Dr. Virginia Penhune at 848-7535 (vpenhune@vax2.concordia.ca). If at any time you have questions about your rights as a research participant, please contact Adela Reid, Research Ethics and Compliance Officer, Concordia University, at 514.848.2424, x.7481 or by email at Adela.Reid@Concordia.ca.