UNIVERSITY OF MINNESOTA

This is to certify that I have examined this copy of a Plan B Project by

Linlu Sun

and have found that it is complete and satisfactory in all respects, and that any and all revisions required by the final examining committee have been made.

Eric E. Hessler, Ph.D. - Advisor

[redacted]

Signature of Faculty Advisor

06/24/22

Date

Musical Training and Improved Visual-Spatial Working Memory, Verbal Working Memory and Processing Speed

A PLAN B THESIS
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA DULUTH
BY

Linlu Sun

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF ARTS

Dr. Eric E. Hessler
July, 2022

Acknowledgements

I would like to express my great appreciation to Dr. Eric E. Hessler for his valuable and constructive suggestions on this study. His patience to give his time has been very much appreciated.

I also would like to extend my thanks to my committee members, Dr. Rebecca Gilbertson and Dr. Paula Gudmundson, for their kind and thoughtful professional suggestions on this study.

Abstract

The current study used a musical skill task—Profile of Music Perception Skills, Mini Version (Mini-PROMS)—to standardize the assessment of musical training for investigating the relationship between musical training and cognitive skills including visual-spatial working memory, verbal working memory, and processing speed. The study also aimed to explore whether musicians who have better verbal working memory do so because they can process information faster (mediation analysis). Thirty-four students from University of Minnesota Duluth participated in the experiment and completed Mini-PROMS and cognitive skill tasks. Musicians had faster processing speed, and those who had better melody skills had better visual-spatial and verbal working memory, as well as processing speed. Musicians who had better accent skills had better processing speed. No mediated correlation was found.

Keywords: musicians, musical training, visual-spatial working memory, verbal working memory, processing speed

Table of Contents

List of Tables

List of Figures

Musical Training and Improved Visual-Spatial Working Memory, Verbal Working Memory and Processing Speed

Musical training has received much attention from musicians, educators, psychologists, and even parents. Researchers have discussed the benefits of musical training (Porflitt & Rosas-Díaz, 2019; Schellenberg, 2016) and how musical training shapes the developing brain (Corrigall & Trainor, 2011; D’Souza & Wiseheart, 2018; Hyde et al., 2019). Musical training improves auditory and motor skills, and can improve other cognitive skills. Researchers have found that musicians have better cognitive skills (Carey et al., 2015) than non-musicians. On the other hand, some studies have not found advantages of musical training for certain cognitive skills (Mehr, 2015; Sala & Gobet, 2017). The current study will focus on the relationship between musical training and cognitive skills including working memory and processing speed.

Musical training involves formal instrumental and vocal training. The focus of this study is on instrumental training. Fundamental elements of musical training involve pitch (frequency of sound waves), timbre (complexity of sound waves), and rhythm (pattern of notes and rests) (Levitin et al., 2018; Ontario Ministry of Education, 2009, p. 18; Pretto & James, 2015). When playing an instrument, musicians learn how to produce exact pitches and timbres following specific rhythm in a bar (D’Souza et al., 2018). Moreover, they learn about rules between sections (a piece of music can have different parts to express different meaning or emotion by changing pitch, rhythm, etc.) to produce harmonic music. This complicated physical activity involves precise motor control and auditory perception, which directly trains perceptive skills of discriminating changes of melody, tuning, accent, and tempo in musical notes (Zentner & Strauss, 2012). The enhanced perception may improve brain activities related to motor sequences, timing, and spatial recognition (Zatorre et al., 2007). This sensory-motor integration may enhance interactions between domains and transfer trained skills to non-musical skills such as working memory and processing speed (Hannon & Trainor, 2007).

Changes in Brain Function and Structure

Evidence from functional magnetic resonance imagery (fMRI) indicates that musicians and non-musicians have different brain morphology. Gaser and Schlaug (2003) found that adult musicians have larger volumes of gray matter in the motor, auditory, and visual-spatial areas of their brain. The difference in brain morphology could be attributed to complex motor and auditory skills training from an early age. A longitudinal study showed that even one year of keyboard training led to structural differences in the brains of 6-year-old children compared to children who did not have the training at the same age (Hyde et al., 2009). From a similar baseline of brain structures, fMRI showed that children in the training group had larger relative voxel sizes in the primary motor and auditory areas and the corpus callosum. The training group also had better motor and auditory performance. The differences in brain structure may therefore be associated with differences in brain function between musicians and non-musicians.

These changes can lead to greater activity in certain brain areas, which include the cerebellum, temporal lobe and lateral cortex (Tan et al., 2010), auditory and motor cortex (Levitin, 2006; Pretto & James, 2015), and occipital and parietal lobes (Petschke et al., 1988). The cerebellum is associated with controlling muscles that produce body movement, the temporal lobe with auditory functions, the lateral cortex with working memory and the inhibition system, the occipital lobe with visual functions, and the parietal lobe with spatial functions. Musical training, specific gestures for playing instruments, producing pitches, hearing tones, reading musical notes, and remembering music pieces may improve functional changes in working memory, and motor, auditory, visual, and inhibitory systems. Therefore, musical training may affect neural processing through a function-structure loop in which functional changes lead to structural changes, which further influence functional changes.

Transfer Skills

Transfer skills theory can explain why musical training can improve cognitive skills that are not directly related to the process of learning music (Royer et al., 2005). Transfer skills theory consists of models that indicate learning one skill, domain, or performance can improve another skill, domain, or performance that is not directly trained (Barnet & Cecci, 2002; D’Souza & Wiseheart, 2018; Hyde et al., 2009; Singley & Anderson, 1989). Instrumental training can directly improve related skills such as motor and auditory skills. For example, Hyde et al. (2009) used the four-finger motor sequencing test to measure motor skills, and the melodic and rhythmic test to measure auditory skills. In the motor skills test, 6-year-old children were instructed to press numbers on a keyboard quickly and correctly; each finger corresponded to a specific number. The auditory test required children to discriminate between paired pitches and paired patterns. Children who received keyboard training had better performance on these tests. This suggests that playing an instrument may benefit fine motor performance, and reading and producing pitches and rhythm may benefit auditory recognition.

Fine motor skills and auditory perception can be classified as near-transfer skills from musical training. Other skills that are less similar to the trained skill can be identified as far-transfer skills (Barnett & Ceci, 2002). Musicians have improved near-transfer skills such as motor performance and auditory perception (Schellenberg, 2016). Most far-transfer skills related to musical training and cognition that have been examined involve visual-spatial and verbal working memory, the ability to process immediate events (Bugos et al., 2007; George & Coch, 2011; Lee et al., 2007), and processing speed, the speed of mental processing of specific tasks (Bugos & Mostafa, 2011; Bull & Johnston, 1997). This study will explore the relationship between musical training and these cognitive skills: visual-spatial and verbal working memory, and processing speed; and the relationship between musical sub-skills (melody, tuning, accent, and rhythm) and these cognitive skills.

Working Memory and Processing Speed

Visual-spatial working memory is a type of working memory that involves remembering the location of stimuli in the visual field. It is required in musical training for reading and remembering musical pieces and producing melodies, so it is one of the cognitive skills frequently compared between musicians and non-musicians. Research has shown that musicians recall the position of pictures or words shown at different locations on screens more accurately than non-musicians (Lehnert et al., 2006; Slevc et al., 2016). Studies have found that elementary to high school students who received musical instruction and instrumental training (two years or less for each grade) had better spatial working memory compared to before they started to receive the training (Hetland, 2000) or age-matched untrained groups (George et al., 2011). These studies suggest that musical training may improve visual-spatial working memory in children and adults.

The method used for testing visual-spatial working memory between musicians and non-musicians have varied. For example, Porflitt and Rosas-Díaz (2019) used the Binding test, and George et al. (2011) used the Memory for Location subtest from the Memory and Learning test. A commonly used visual-spatial working memory test is the Symmetry Span task. Vuvan et al. (2020) used the symmetry span task—which requires participants to remember the location of presented red squares with interruptions of symmetric judgment questions—to examine the relation between musical training and visual-spatial working memory. They found a reliable positive link between musical training and visual-spatial working memory.

Recently, researchers have focused more on verbal working memory (an important cognitive domain for language) in musicians, which is based on far-transfer theory (Porflitt et al., 2019). It has been acknowledged that music is another unique language that humans use to communicate (Jentschke & Koelsch, 2009; Moreno & Besson, 2006). Remembering a piece of music and performing it is similar to remembering and reciting a piece of text, and the potential overlapping domains may help improve the development of language (Moreno et al., 2011). Learning music theory and playing an instrument helped ten-year-old children develop syntax processing (Jentschke, & Koelsch, 2009). Expressions of pitch, accent and harmony in music may be similar to vocabulary, emphasis, and syntax of language. Franklin et al. (2008) found that musicians had a longer verbal memory span compared to non-musicians. For example, on average, musicians could recall 7-digit spans correctly, whereas non-musicians could recall 5-digit spans.

Researchers have also studied tonal and verbal working memory related to musical training. Lu (2012) used an adaptive N-back task exploring the correlation. Lu asked participants to detect similarities between pairs of Mandarin words. Participants judged whether or not the words were homophones, and whether or not they were similar in expressive tone (there are four tones in Mandarin words). Participants compared the current word to the immediately previous word (1-back) or to a word that came before the immediately previous word (2-back). Musicians were more accurate than non-musicians in discriminating homophones and tone in the 1-back task, and in discriminating tone in the 2-back task. Moreover, a longitudinal study showed that instrumental training can benefit children and adolescents regarding their verbal memory (Nutley, 2014). It can be implied that the improved auditory perception of musical training may transfer to verbal domains. It is possible that the improved melody and accent perception from musical training may benefit phonology (speech sounds that contribute to meaning), morphology (meaning at the smallest level of speech), and tone (grammatical mood) in language, and it may expand verbal memory span to help people learn these aspects of language.

Processing speed is another skill that researchers found improved with musical training (Roden et al., 2014). Processing speed is the speed of mental processes regarding a task, which can be observed by the velocity of the cognitive task or the accuracy of the performance of the task with limited reaction time. Training and learning are believed to affect experience-based functional changes within a specific domain (Bull & Johnston, 1997; Kail, 1991). Aspects of musical training, including improving perceptive skills of melody and accent, reading notes, and producing music, may improve processing speed regarding visual, auditory, and motor functions

(Sares et al., 2018). Bugos and Mostafa (2011) tested accuracy of auditory and visual processing speed tasks (Paced Auditory Serial Addition Test and Trail Making Test). For the auditory test, participants heard a series of digits and reported the sum of last two digits as far as they could. For the visual test, participants drew lines to connect numbers, letters, or numbers and letters in sequence from point to point as fast as they could. Musicians performed better than non-musicians on both processing speed tests.

Previous literature supports associations between musical training and different types of working memory, and musical training and processing speed. Given these connections, musical training and processing speed may interact to improve working memory. Fry and Hale (2000) suggested that improved processing speed may predict better working memory. Moreover, previous studies have posited that processing speed can be a mediator between musical training and working memory (Benz et al., 2016; Schellenberg, 2006, 2016; Slevc et al., 2016). Brown et al. (2012) found that performance on the Four-Choice Reaction Time Task (for processing speed) predicted visual working memory (performance on the Visual Patterns Test). Given the evidence from previous literature that musical training can both improve processing speed and working memory, it can be implied that musical training may improve processing speed and therefore improve different types of working memory including visual working memory.

The current study analyzed the relationships between musical training and cognitive skills including two types of working memory and processing speed. I first hypothesized that participants who have better music skills would have better visual-spatial and verbal working memory, as well as processing speed than non-musicians. Secondarily, I hypothesized that musical sub-skills—melody and accent skills—

would be correlated with the three cognitive skills, such that musicians who have better melody and accent skills may have better cognitive skills. Finally, I explored that processing speed may mediate the relation between musical training and working memory, which means musical training may improve working memory by improving processing speed.

Method

Participants

Thirty-five individuals who were 18 years of age or older with normal or corrected to normal vision and hearing participated in this study. Participants either received research participation credit toward a psychology course or a $10 gift card in exchange for their participation. Twenty-three participants identified as female and 12 as male. Twenty-five participants identified as White, one as Asian and one as Venezuelan. Participants ranged in age from 18 to 24 years. Thirteen participants had no formal musical training and 25 had formal musical training, including seven who majored in music. Three participants with no formal musical training and all participants with formal musical training could read western musical notation. Types of musical training included the piano (10 participants), guitar (7), violin (3), trumpet (4), trombone (1), cello (2), saxophone (5), ukulele (5), clarinet (6), flute (1), percussion (5), euphonium (1), bass (2), and voice (4). Fifteen participants had more than one type of instrumental and/or vocal training: Guitar and drums/percussion (2); guitar and ukulele (1); guitar and flute (1); piano and drums/percussion (2); trumpet, ukulele, cello, guitar and piano (2); saxophone, drums/percussion, trumpet and clarinet (1); clarinet and saxophone (1); piano and voice (1); bass, ukulele, voice and piano (1); piano, clarinet, voice and ukulele (1); bass, saxophone, guitar, piano and voice (1); and euphonium, piano, trombone, clarinet and trumpet (1). Most participants with formal musical training no longer played, but many still practiced 0–5 hours per week. Participants were treated in accordance with the ethical principles of the American Psychological Association. The study was approved by the University of Minnesota Institutional Review Board.

Materials

To assess musical ability, we used the Profile of Music Perception Skills, Mini Version (Mini-PROMS; Zentner & Strauss, 2017), which had four subtests (Melody, Metric Accent, Tempo, and Tuning). Each subtest had ten to twelve trials. Mini-PROMS took around 15 minutes to complete. Participants determined whether two stimuli were the same or different. For instance, in the Melody subtest, participants listened to a target melody twice. Then, they listened to another melody that was either the same or slightly different. Participants then chose whether the melodies were definitely the same, probably the same, probably different, definitely different, or if they did not know if they were the same or different. Each subtest had the same number of "same" and "different" trials.

Correct answers for definitely same or different were counted as two points. Correct answers for probably same or different were counted as one point. All incorrect answers received no points. To compute the subtest scores, points on all items were summed and divided by two. The total test score was the sum of all subtest scores. The highest possible score on the Mini-PROMS was 36. The score of each subtest was also collected. In previous research, participants who scored higher than 27.5 with formal musical training, between 18 and 27.5 with musical experience, and below 18, have been classified as professional musicians, amateur musicians, and non-musicians, respectively (Zentner & Strauss, 2017).

Internal consistency of Mini-PROMS in this study was acceptable (r_{tt}^{a} = .79), which was similar to the internal consistency that Zentner and Strauss (2017) reported (r = .81). Table 1 shows descriptive statistics and correlation of Mini-PROMS with years of training. Musical ability was significantly correlated with training years, $r(34) = .66$, $p < .001$.

Table 1

Descriptive Statistics and Correlation for Mini-PROMS and Years of Musical Training

Scale	*M*	*SD*	1	2
1. mini-PROMS	22.18	4.49	—	
2. Training years	5.76	5.57	.66*	—

Note. N = 34. Mini-PROMS = the score of music ability.

$^{*}p < .01$.

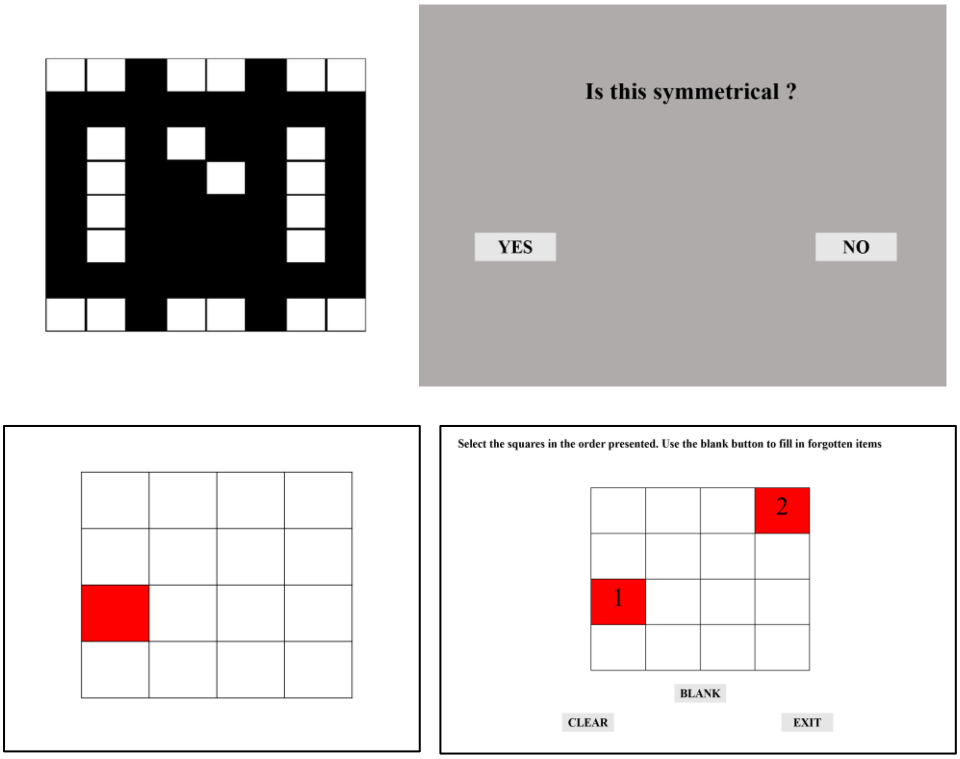
Fisher’s exact test was used to determine if there was a significant association between the Mini-PROMS score (above versus below the median of 22.25) and the current number of hours practiced per week (at or above 6 hours versus below 6 hours). There was a significant statistical association between the median Mini-PROMS score and the current number of hours practiced per week, $\chi_F^2 = 5.89$, $p = .04$. Of the 17 participants who scored below the median on the Mini-PROMS, 16 practiced less than 6 hours per week and one practiced more than 6 hours per week. Of the 17 participants who scored above the median on the Mini-PROMS, 10 practiced less than 6 hours per week and 7 practiced more than 6 hours per week. Regarding convergent validity, Zentner and Strauss (2017) found that Mini-PROMS positively correlated with other musical skill tests (e.g. Musical Ear Test, Musical Aptitude Profile; *r* [.44, .64]).

The Automated Symmetry Span Task (Vuvan et al., 2020, adapted from Conway et al. , 2005) was used to assess visual-spatial working memory. Participants attempted to remember the order of the presentation of red squares that were randomly presented in a 4x4 matrix (see Figure 1). Before the presentation of each red square, participants were shown a pixelated black and white image on the screen and then judged whether or not the image was symmetric. Data from the Automated Symmetry Span Task for participants who had scores below 85% on these symmetry judgment questions were excluded from analyses. The symmetry judgment was followed by the presentation of a red square in a 4x4 matrix. This sequence (pixelated image, symmetry judgment, red square) continued between two and five times. Participants were asked to recall the locations of the red squares in the order they were presented by clicking on squares in a blank 4x4 matrix. There were 12 trials in total, with three repetitions of each of the four set sizes.

The duration of sentence presentation in the formal test was the average of the processing time of judgment speed during a practice session. Participants would view the image as long as they pleased, then clicked to determine whether the image was symmetric or asymmetric. In the formal test, if participants ran over reading time, it would automatically skip the judgment sentence and record an error. In the square recall task, if a participant forgot the order of the presented location of one of the squares in a set, they were instructed to click “blank” instead.

Figure 1

Automated Symmetry Span Task



Is this symmetrical ?

Select the squares in the order presented. Use the blank button to fill in forgotten items

Note. A pixelated black and white image (upper left) followed by a symmetry judgment (upper right), which was then followed by a red square presented in a 4x4 matrix (bottom left). That pixelated image, symmetry judgment, red square sequence repeated between two and five times. The image and square presented differed from one repetition to another. After completion of a sequence, participants clicked all the locations of the red squares in the order in which they were presented (bottom right).

Two measures were used from the Automated Symmetry Span Task: Symmetry Span (SSPAN) and Symmetry Total Correct (Redick et al., 2012). For SSPAN, each correctly recalled square in each perfectly recalled set counted as one point. For example, if the participant recalled the correct location and order of squares in the set size of three, two squares in a set size of four, and five squares in a set size of five, then the participant's score would be 8 (3 + 0 + 5). In contrast, for Symmetry Total Correct, each correctly recalled square counted as one point, regardless of whether the square was part of a perfectly recalled set.

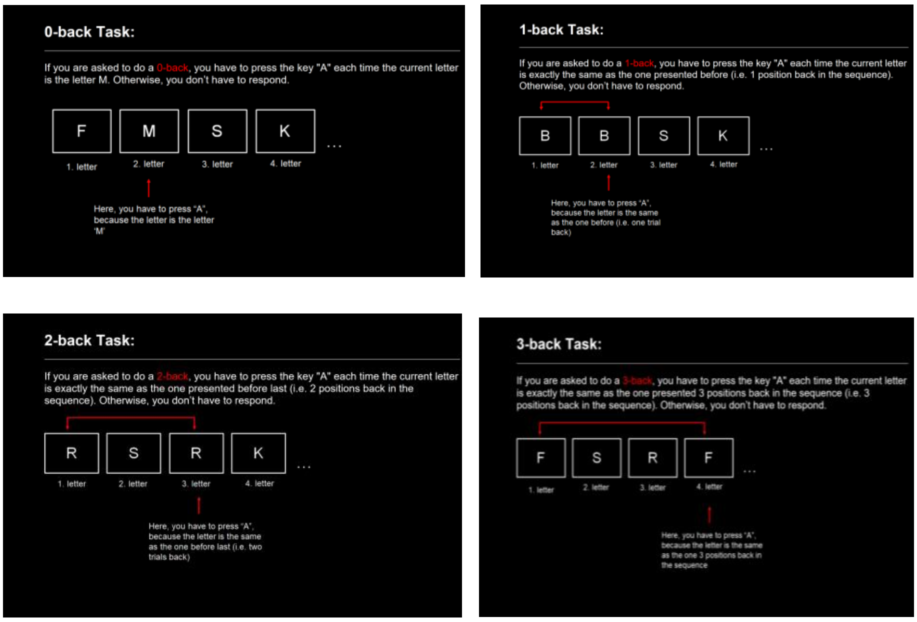
The Automated Symmetry Span Task in this study had good internal consistency ($r_{tt}^{a} = .80$), which was consistent with previous studies ($r = .81$) (Conway et al., 2005; Redick et al., 2012). The test-retest reliability from minutes to years was appropriate (r [.70, .80]) in a previous study (Conway et al., 2005). Previous studies indicated that the Automated Symmetry Span Task was associated with high activity in dorsal prefrontal cortex (Magnuson et al., 2015), an area of the brain related to spatial working memory. Moreover, the Automated Symmetry Span Task had appropriate construct validity in Conway et al. (2005), exhibiting high intercorrelations with both higher order (e.g., following oral and spatial directions) and lower order (e.g., attention and perception tasks) cognitive tasks, and a high correlation with the rotation span task (Draheim et al., 2018).

The Single N-Back Task (Letters stimuli) was used to assess verbal working memory (Ragland et al., 2002). In the single n-back task, participants viewed a sequence of 20 consonants on a screen (see Figure 2). There were four trial types: $n = 0$, $n = 1$, $n = 2$, or $n = 3$ (order pseudorandom). Participants pressed "A" whenever the target consonant was presented on the screen ($n = 0$), if the consonant was the same as the one that preceded it ($n = 1$), if the consonant was the same as the one presented two positions back ($n = 2$), or if the consonant was the same as the one presented three positions back ($n = 3$). In all trial types, if the criteria for the presented consonants were not met, participants were instructed not to respond. Each consonant was presented on the screen for 500 ms. There was a 2000 ms delay before the next consonant was presented. Participants could respond any time within the 2500 ms period. Participants practiced at least nine trials (the number of practice trials could vary because participants could choose to practice more) per level *n* before doing the formal task. No performance criterion was required for N-back task. After the practice trials, there were 15 experimental trials; 5 presented a target and 10 did not. The computer randomly selected the target trials and the target consonant.

Only the data collected during the experimental trials were used for analyses. For each level *n*, the system determined hit rate, false alarm rate, and mean hit response time. I will illustrate these variables using the 1-back task. A hit was recorded when a participant pressed the letter “A” on the keyboard when the consonant on the screen was the same as the one that preceded it. Hit rate was the number of hits out of the number of times the consonant presented was the same as the preceding consonant. A false alarm was recorded when a participant pressed the letter “A” when the consonant presented was different from the preceding consonant. False alarm rate was the number of false alarms out of the number of times the consonant presented was different from the preceding consonant. Mean hit response time was the average time (ms) across all instances that the participant correctly pressed the letter “A”. D-prime was also calculated. Higher d-primes represented maximizing the hit rate while also minimizing the false alarm rate. The only measure I am submitted to analyses for the N-back tasks is d-prime. The overall, $n = 2$, and $n = 3$ d-prime were recorded for analyses. I refer to those variables as Nback, Nback-2, Nback-3 in the results section.

Figure 2

Single N-Back Task



0-back Task:

If you are asked to do a 0-back, you have to press the key "A" each time the current letter is the letter M. Otherwise, you don't have to respond.

Here, you have to press "A", because the letter is the letter 'M'

1-back Task:

If you are asked to do a 1-back, you have to press the key "A" each time the current letter is exactly the same as the one presented before (i.e. 1 position back in the sequence). Otherwise, you don't have to respond.

Here, you have to press "A", because the letter is the same as the one before (i.e. one trial back)

2-back Task:

If you are asked to do a 2-back, you have to press the key "A" each time the current letter is exactly the same as the one presented before last (i.e. 2 positions back in the sequence). Otherwise, you don't have to respond.

Here, you have to press "A", because the letter is the same as the one before last (i.e. two trials back)

3-back Task:

If you are asked to do a 3-back, you have to press the key "A" each time the current letter is exactly the same as the one presented 3 positions back in the sequence (i.e. 3 positions back in the sequence). Otherwise, you don't have to respond.

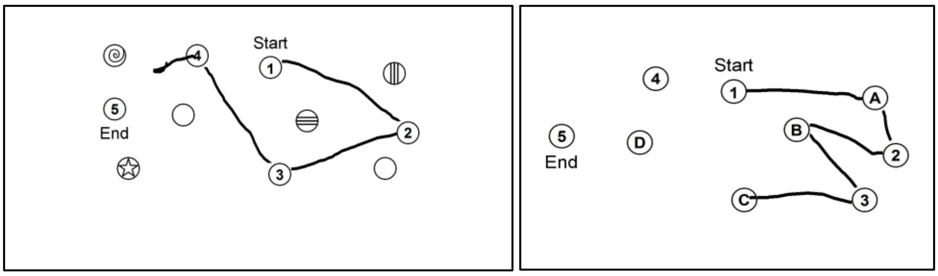
Here, you have to press "A", because the letter is the same as the one 3 positions back in the sequence

Note. Participants were shown a sequence of consonants (from a pool of 20) on a screen and were asked to press "A" to indicate whether the currently presented consonant fulfills the following criteria: for *n* = 0 trials, is the letter the same as the letter 'M'?; for N=1 trials, is the letter the same as the one that preceded it?; for *n* = 2 trials, is the letter the same as the one presented two positions back?; for *n* = 3 trials, is the letter the same as the one presented three positions back? If so (it's a target), and they were instructed to press "A". If not, they were instructed not to respond.

The study used the Trail Making Test (A & B) to assess psychomotor processing speed (Reitan, 1955). Participants moved the mouse in a predetermined sequence as fast as they could. There were four trails—which were sample A, trail A, sample B, and trail B—in total (see Figure 3). On A trails, 25 numbers surrounded with circles (1-25) were presented on the screen. Participants drew lines as fast as they could with their mouse from 1 to 25 in numeric order. On B trails, 13 numbers (1–13) and 12 letters (A–L) were surrounded with circles. Participants drew lines as fast as they could between the numbers and letters with the specific sequence from 1-A-2-B, etc. The times in milliseconds that participants took to complete trails A and B were recorded independently. The sum of times for the two parts was recorded as performance of processing speed.

Figure 3

Trail Making Test



Note. In sample A (left panel), participants drew lines from 1 to 5 in a numeric order with the mouse as fast as they could. In sample B (right panel), participants linked numbers and letters in a specific sequence from 1-A-2-B, etc. as fast as they could.

Procedure

The entire testing session was approximately 50 minutes in length, which was composed of the demographic survey, the musical skills test and cognitive tests. The study was conducted both online and in lab. Participants first completed musical skills task (Mini-PROMS), with questionnaires for general background, education information and musical background information at the beginning. Then they participated in the cognitive skill tests (Automated Symmetry Span Task, N Back

Task [Letter stimuli], and Trail Making Task). The order in which the cognitive skill tests were presented was counterbalanced across participants using a Latin Square. For participants who conducted the experiment online, they received an email with a link to participate by using a computer or laptop, a mouse, and earphones. Participants were instructed to use wired earphones (not Bluetooth earphones or airpods), a laptop and mouse to do Mini-PROMS. Cognitive tests required that participants had a clear screen, keyboard and mouse to click. For participants who conducted the experiment in the lab, they were instructed by the experimenter and supplied with equipment. All cognitive tasks were available in INQUISIT 6 (Millisecond).

Data Analyses

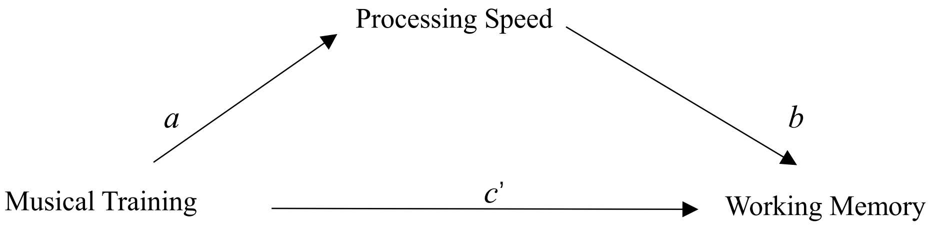
Statistical Analyses. All data were analyzed in IBM SPSS Statistics 27. The first hypothesis that musicians would perform better in two types of working memory and processing speed tasks, was analyzed using Pearson's *r*. For all tasks, the participant variables were the overall and subtest scores on the mini-PROMS. Dependent variables were scores on the Automated Symmetry Span task, N Back task (Letter stimuli), and Trail Making task. All pairwise correlations were calculated between the above measures. In addition, *t*-tests were used to compare performance on each dependent variable for participants with low versus high scores on Mini-PROMS and its subtests. The two Mini-PROMS groups were determined based on a median split. The two groups on each subtest were determined based on the median split of each subtest. These *t*-tests are likely statistically underpowered due to limited sample size.

Mediation Analyses. A mediation model was constructed to test the second hypothesis that processing speed mediates the relationship between musical training and working memory (Figure 4). The total effect of musical training on working memory, *c*, can be partitioned into the direct effect of musical training on working memory (*c*') and the indirect effect of musical training on working memory, through processing speed (*ab*), such that $c = ab + c'$ (Figure 4). I ran the mediation analysis four times with each working memory variable. Of particular interest in my analyses was whether the indirect (i.e., mediating) effect *ab* was a significant predictor in modeling working memory. Significance testing of the mediating effect of musical training → processing speed → working memory (quantified by *ab*) was carried out via a bootstrapping analysis with 5000 iterations (Hayes, 2017). These mediation analyses are likely statistically underpowered due to limited sample size.

Validity Analyses. For examining the validity of the Mini-PROMS, *t*-tests were used compare participants with versus without formal musical training on the Mini-PROMS and each subtest. Moreover, *t*-tests were also used to compare participants who could read versus could not read western musical notation on the Mini-PROMS and each subtest.

Figure 4

Schematic of the Predicted Mediation Model



Note. The mediation model that processing speed mediate the correlation between musical training and working memory. The direct effect is the effect of musical training on working memory (*c*') and the indirect effect is musical training on working memory, through processing speed (*ab*).

Results

Data Cleaning and Transformation

The assumptions of normality were verified. The variable, symmetry total recalls, was negatively skewed. This issue was corrected by reverse scoring and then taking the square root. Data from one participant with prior musical training was excluded because the version of the macOS operating system on their laptop was not compatible with Inquisit 6. Due to a graphics issue on certain Windows operating systems, 27 participants completed the N-back task, compared to 33 who completed the Trail Making test. All participants completed the Symmetry Span task. However, only 31 participants reached 85% accuracy on the symmetry judgments, which was the attention criterion. In total, the study included 34 participants, of which 31 for Symmetry, 27 for N-back, and 33 for Trail Making were included in the data analyses (pairwise deletion).

Mini-PROMS and Cognitive Tasks

Table 2 shows descriptive statistics and correlations of the total score on mini-PROMS and the score on each cognitive task. Only the correlation between mini-PROMS and Trail Making was significant, $r(33) = -.42$, $p = .01$. A smaller trail making score from the total of A and B indicates that participants completed the task more quickly. Participants who had better music skills tended to have faster processing speeds.

The effects for low vs. high Mini-PROMS on Nback, $t(25) = 1.829$, $p = .08$, $d = 0.71$, and Trail Making, $t(31) = 1.728$, $p = .09$, $d = 0.60$, trended toward significance. Performance on those cognitive tasks trended better in the high Mini-PROMS group [Nback, $M(12)= 3.17$, $SD = 0.72$; Trail Making, $M(16)= 78165.88$, $SD = 15880.88$]

than the low Mini-PROMS group [Nback, *M*(15)= 2.61, *SD* = 0.84 and Trail Making, *M*(17)= 88653.82, *SD* = 18754.91]. The effects for low vs. high Mini-PROMS on SSPAN, *t*(29) = .880, *p* = .39, *d* = 0.32; SR_STC, *t*(29) = .682, *p* = .50, *d* = 0.25; Nback-2, *t*(25) = 1.527, *p* = .14, *d* = 0.59; and Nback-3, *t*(25) = 1.418, *p* = .17, d = 0.55, were not significant.

Table 3 shows descriptive statistics and correlations of the score on each subtest of mini-PROMS and the score on each cognitive task. There were significant correlations between the Melody subtest and reverse scored and square root of symmetry total correct (SR_STC), *r*(31) = –.38, *p* = .04, Melody and Nback, *r*(27) = .43, *p* = .03, Melody and Trail Making , *r*(33) = –.47, *p* = .04, and Accent and Trail Making, *r*(33) = –.38, *p* = .03. Smaller SR_STC and trail making scores indicated better performance on those tasks. Participants who had higher melody scores tended to have better visual-spatial working memory, verbal working memory (in the simplest Nback task), and processing speed. Participants who had higher accent scores tended to have better processing speed.

The effect of low (*M* = 2.61, *SD* = 0.84) vs. high (*M* = 3.02, *SD* = 0.71) Mini-PROMS on Nback, *t*(25) = 1.812, *p* = .09, *d* = 0.76, trended toward significance. With that exception, no other comparisons of low vs. high Melody scores (*Mdn* = 6), Tuning scores (*Mdn* = 5), Accent scores (*Mdn* = 5.5), or Tempo scores (Mdn = 5.25) approached significance on any of the cognitive tasks. For Melody: SSPAN, *t*(29)= 1.148, *p* = .26, *d* = 0.42; SR_STC, *t*(29) = 1.615, *p* = .12, *d* = 0.59; Nback, *t*(25)= 1.458, *p* = .16, *d* = 0.57; Nback-2, *t*(25) = 1.183, *p* = .25, *d* = 0.46; Nback-3, *t*(25)= 0.650, *p* = .52, *d* = 0.25; Trail Making, *t*(31)= .216, *p* = .83, *d* = .07. For Tuning: SSPAN, *t*(29) = .959, *p* = .35, *d* = 0.35; SR_STC, *t*(29) = 0.723, *p* = .48, *d* = 0.3;

Nback, *t*(25) = .027, *p* = .98, *d* = 0.01; Nback-2, *t*(25) = .510, *p* = .61, *d* = 0.2; Nback-3, *t*(25) = .593, *p* = .56, *d* = 0.2; Trail Making, *t*(31) = .108, *p* = .92, *d* = 0.57. For Accent: SSPAN, *t*(29) = .222, *p* = .83, *d* = 0.08; SR_STC, *t*(29) =.799, *p* = .44, *d* = 0.29; Nback-2, *t*(25) = .714, *p* = .48, *d* = 0.28; Nback-3, *t*(25) = 1.610, *p* = .12, *d* = 0.62; Trail Making, *t*(31) = 1.633, *p* = .11, *d* = 0.57. For Tempo: SSPAN, *t*(29) = .088, *p* = .93, *d* = 0.03; SR_STC, *t*(29) = .358, *p* = .72, *d* = 0.13; Nback, *t*(25) = –.713, *p* = .48, *d* = 0.28; Nback-2, *t*(25) = .249, *p* = .81, *d* = 0.1; Nback-3, *t*(25) = .737, *p* = .47, *d* = 0.28; Trail Making, *t*(31) = 0.911, *p* = .37, *d* = 0.32.

Table 2

Descriptive Statistics and Correlations for Mini-PROMS and Cognitive Tasks

Scale	*n*	*M*	*SD*	Skew	1	2	3	4	5	6	7	8
1. mini-PROMS	34	22.18	4.49	–0.31	—							
2. SSPAN	31	21.94	8.15	0.24	.08	—						
3. STC	31	42.53	4.60	–1.10	—	—	—					
4. SR_STC	31	3.15	0.95	0.17	–.10	–.91**	—	—				
5. Nback	27	2.86	0.83	–0.85	.35	.59**	—	.70**	—			
6. Nback-2	27	3.06	1.47	–0.21	.23	.74**	—	.79**	.81**	—		
7. Nback-3	27	1.89	1.17	–0.46	.30	.37	—	.42*	.83**	.46*	—	
8. Trail making	33	83568.76	17956.22	0.17	–.42*	–.00	—	.00	.00	.00	.00*	—

Note. Mini-PROMS = the score of music ability. SSPAN = number of correctly recalled squares in each perfectly recalled set; a measure of visual spatial working memory. STC = total number of correctly recalled squares; a measure of the capacity of visual spatial working memory. SR_STC = Reverse scored and square root of STC. Nback = d-prime for all trials; Nback-2 = d-prime for trial n = 2; Nback-3 = d-prime for trial n = 3; measures of verbal working memory. Trail making = time (ms) to complete Trails A and B; a measure of processing speed.

$^{*}p < .05$, $^{**}p < .01$

Table 3

Descriptive Statistics and Correlations for Mini-PROMS Subtests and Cognitive Tasks

Scale	*n*	*M*	*SD*	1	2	3	4	5	6	7	8	9	10
1. Melody	34	6.06	1.60	—									
2. Tuning	34	5.13	1.47	.52**	—								
3. Accent	34	5.75	1.52	.55**	.46**	—							
4. Tempo	34	5.21	1.47	.25	.27	.26	—						
5. SSPAN	31	—	—	.30	.07	–.04	–.10	—					
6. SR_STC	31	—	—	–.38*	–.07	.00	.17	–.91**	—				
7. Nback	27	—	—	.43*	.17	.27	.12	.59**	.70**	—			
8. Nback-2	27	—	—	.34	.21	.09	.02	.74**	.79**	.81**	—		
9. Nback-3	27	—	—	.32	.07	.21	.26	.37	.42*	.83**	.46*	—	
10. Trail making	33	—	—	–.37*	–.30	–.38*	–.25	.00	.00	.00	.00	.00*	—

Note. Mini-PROMS = the score of music ability. SSPAN = number of correctly recalled squares in each perfectly recalled set; a measure of visual spatial working memory. STC = total number of correctly recalled squares; a measure of the capacity of visual spatial working memory. SR_STC = Reverse scored and square root of STC. Nback = d-prime for all trials; Nback-2 = d-prime for trial n = 2; Nback-3 = d-prime for trial n = 3; measures of verbal working memory. Trail making = time (ms) to complete Trails A and B; a measure of processing speed.

*p < .05, **p < .01

Mediation Analysis

Table 4 shows the indirect effects and biased corrected 95% confidence intervals of simple mediation models as shown in Figure 4 and serial mediation model. The descriptive statistics of each path appear in the Appendix B. Based on the confidence intervals, none of the indirect effects of models were significant. Processing speed did not mediate the relationship between mini-PROMS or its subtests and visual-spatial or verbal working memory.

Table 4

Mediation Model Indirect Effects

Model	Indirect effects	*SE*	95% CI	
			LL	*UL*
Mini-PROMS– PS– SSPAN	.21	.20	–.13	.66
Mini-PROMS– PS– SR_STC	–.02	.02	–.07	.24
Mini-PROMS– PS– Nback	–.28	.03	–1.06	1.27
Mini-PROMS– PS– Nback-2	.01	.03	–.06	.09
Mini-PROMS– PS– Nback-3	.04	.04	–.02	.13
Melody– PS– SSPAN	.35	.41	–.38	1.26
Tuning– PS– SSPAN	.50	.52	–.53	1.59
Accent– PS– SSPAN	.70	.69	–.16	2.49
Tempo– PS– SSPAN	.33	.46	–.30	1.54
Melody– PS– SR_STC	–.03	.05	–.13	.08
Tuning– PS– SR_STC	–.05	.06	–.18	.08
Accent– PS– SR_STC	–.07	.08	–.27	.04

Model	Indirect effects	*SE*	95% CI	
			LL	*UL*
Tempo– PS– SR_STC	–.04	.05	–.18	.04
Melody– PS– Nback	.04	.05	–.04	.17
Tuning– PS– Nback	.06	.08	–.08	.25
Accent– PS– Nback	.05	.06	–.05	.19
Tempo– PS– Nback	.04	.05	–.03	.20
Melody– PS– Nback-2	.01	.06	–.11	.17
Tuning– PS– Nback-2	.03	.10	–.18	.26
Accent– PS– Nback-2	.04	.09	–.10	.26
Tempo– PS– Nback-2	.03	.07	–.07	.22
Melody– PS– Nback-2	.10	.08	–.02	.30
Tuning– PS– Nback-3	.13	.13	–.13	.39
Accent– PS– Nback-3	.11	.08	–.04	.29
Tempo– PS– Nback-3	.08	.09	–.04	.30

Note. The number of participants in models with VS and SR_STC = 31. The number of participants in models with Nback, Nback-2, and Nback-3 = 27. Numbers of bootstrap samples for percentile confidence intervals are 5000. SSPAN = number of correctly recalled squares in each perfectly recalled set; a measure of visual spatial working memory. STC = total number of correctly recalled squares; a measure of the capacity of visual spatial working memory. SR_STC = Reverse scored and square root of STC. Nback = d-prime for all trials; Nback-2 = d-prime for trial n = 2; Nback-3 = d-prime for trial n = 3; measures of verbal working memory. Trail making = time (ms) to complete Trails A and B; a measure of processing speed. CI = confidence interval; *LL* = Lower limit; *UL* = upper limit.

Validity Analyses

Table 5 shows the results of between group analyses examining the effects of formal musical training and ability to read western musical notation on Mini-PROMS and each of its subtests. The effects of musical training and ability to read western musical notation on Mini-PROMS scores, Melody scores, Tuning scores, and Accent scores, were significant. In each case, scores were better for participants with formal musical training or ability to read western musical notation. There were no significant effects of musical training or ability to read western musical notation on Tempo scores.

Table 5

Between Groups Analyses Examining the Effects of Formal Musical Training and Ability to Read Western Musical Notation on Mini-PROMS and its Subtests

Variables	Formal musical training				*t*(32)	*p*	Cohen's *d*	Read musical notation				*t*(32)	*p*	Cohen's *d*
	No ^{a}		Yes ^{b}					No ^{c}		Yes ^{d}				
	M	*SD*	*M*	*SD*				*M*	*SD*	*M*	*SD*			
Mini-PROMS	18.46	3.28	24.48	3.49	4.99	<.001	1.76	18.00	3.27	23.92	3.73	4.36	<.001	1.64
Melody	5.08	1.53	6.67	1.35	3.17	.003	1.19	4.90	1.71	6.54	1.31	3.04	.005	1.14
Tuning	4.08	1.34	5.79	1.16	3.95	<.001	1.39	3.80	1.27	5.69	1.18	4.16	<.001	1.57
Accent	4.58	0.86	6.48	1.39	4.91	<.001	1.56	4.75	0.68	6.17	1.59	2.69	.010	1.01
Tempo	4.73	1.52	5.50	1.39	1.51	.140	0.53	4.55	1.57	5.48	1.36	1.73	.090	0.65

Note. ^{a} *n* = 13. ^{b} *n* = 21. ^{c} *n* = 10. ^{d} *n* = 24.

Discussion

The results of this study partially supported the first hypothesis that individuals with better musical skills have better cognitive skills, specifically for the processing speed measure. The secondary hypotheses that melody skill is the musical sub-skills that correlate with cognitive skills was fully supported. However, the secondary hypotheses that accent skill is the musical sub-skills that correlate with cognitive skills was partially supported. Specifically, musicians who had better melody skills had better verbal and visual-spatial working memory, and processing speed. Moreover, musicians who had better accent skills also had better processing speed. The musical sub-skills, tune and tempo, were not correlated with any cognitive skills. The exploratory hypothesis regarding the mediation of processing speed between musical skill and the two types of working memory was not supported. For the purposes of this discussion, the focus is on correlational analyses where cognitive tasks are the dependent variable, because the corresponding *t*-tests are likely statistically underpowered.

The results regarding verbal working memory showed that musicians who have better melody skills tended to have better verbal working memory. This evidence is consistent with findings by Lu (2012) who used the same N-Back test but with the homophones and expressive tones of Mandarin words as the stimuli and Porflitt et al. (2020) who used a visual digit span task that required participants to recall a sequence of digits in either normal or reversed order. The results are also consistent with findings by Talamini et al. (2016) who used Mini-PROMS for musical ability and revealed that musicians who have better melody skills also have better verbal working memory, in their case by using a digit span task with hybrid-stimuli (auditory, audiovisual, visual) that required participants to recall sequences of digits in order by hearing, hearing and vision, and only visual presentation.

Unlike Lu (2012), musicians in the current study did not perform better in verbal working memory when the difficulty of the N-back task got harder. In Lu’s study, musicians performed better in discriminating homophones in the 1-back task and tones in the 2-back task. One explanation is that Lu’s study used hybrid-Mandarin (expressive tones for audition and homophones for vision) verbal stimuli, while this study used visual-verbal stimuli only. Talamini et al. (2016) suggested that musicians have a better verbal working memory, especially when using auditory stimuli. This suggests that differences between the difficulty levels of the task may be more apparent if we use auditory stimuli. Furthermore, Lu (2012) used two demands (expressive tones and homophones), while my study used a single demand (letters). This suggests that musicians may perform better in verbal working memory when the task gets harder.

In my study, visual-spatial working memory was not correlated with overall musical ability, which was consistent with most studies (Mehr, 2015; Porflitt & Rosas, 2020a &b). However, there was a correlation between the melody skills and the partial score of visual-spatial working memory, which indicates that musicians who have better melody skills tend to have a larger capacity of visual-spatial working memory. This was explained by Hayword and Gromoko (2009) who suggested that the ability of music sight-reading (reading, hearing, singing, and performing unfamiliar notes) relies on aural pattern recognition and spatial-temporal reasoning. My study suggests that reading western notes is probably similar to remembering the position of symbols presented on a specific staff, which requires the basic use of visual-spatial working memory. Recognizing a piece of melody may not only trigger auditory working memory skills but also an enhanced association with visual-spatial working memory.

Regarding processing speed, my data showed a negative correlation between music ability in general and processing speed, which indicates that musicians have better processing speed. Moreover, the results showed that musicians who have better melody and accent skills also had better processing speed. This is consistent with Bugos and Mostafa (2011) and suggests that musicians with the criteria of consistently developed musical skills, more years of training, and higher weekly practice frequencies have better visual processing speed. The finding is also consistent with a longitudinal study by Saarikivi et al. (2019), who found by using Trail Making tasks that 9- to 18-year-old participants—especially 18-year-olds—who all started musical training at around 7 years old have better processing speed. Years of musical training may improve complex informational processing speed, and professional or amateur musicians may have faster visual processing speed.

My study identified a correlation between melody and processing speed. This is inconsistent with Porflitt and Rosas (2020b) who, to my knowledge, published the only other study that examined this relationship. They separated musicians who had different musical training into rhythmic (e.g., cymbal), melodic (e.g., flute), and harmonic (e.g., piano) groups, and they found no differences in processing speed across these groups. It is possible that processing speed may be correlated with melody skills, but not with different types of training.

To my knowledge, there are no previous studies on the relationship between accent skill and processing speed. According to Law and Zentner (2012), accent addresses the ability to discriminate the emphasis of notes, and the harder the test, the smaller changes in the intensity of the emphasis, which required a more sensitive perceptive skill. In other words, the faster the processing speed, the more sensitive perceptive skills were to capture the emphasis in notes or speech. According to the study of tonal contrast and accent or word emphasis in speech (Felder et al., 2009), participants were instructed to identify the correct syllable (target tonal word) in Swedish between two options: a rising tone first with stressed syllable last, or a falling tone with a second peak without a given stressed syllable. They found that participants found the target tonal word faster and more accurately when the word had the last syllable stressed. Because tonal speech has specified rising or falling tones of syllables, it is similar to musical "syllables" within melody. Therefore, the current study suggests that accent of musical notes may help information to process faster, which could allow musicians to read and perform notes accurately.

Based on my results, processing speed did not mediate overall music skill or detailed music skills and different types of working memory. This is inconsistent with previous literature that processing speed may be a predictor of working memory (Fry & Hale, 2000). One explanation can be that I used different measurements of processing speed—Trail Making task, while previous studies of processing speed and working memory used Symbol Search tasks for matching the stimuli such as pictures or numbers. The Trail-Making task requires both visual information processing and motor-responding for linking numbers and letters in numerical sequence, while Symbol Search only requires visual processing by simply clicking or tapping on one target. The current study suggests that Symbol Search tasks may overlap more to working memory rather than musical skills, which impacts the mediating relationship of processing speed between musical training and working memory.

Another explanation of the lack of mediation can be that previous literature used more tasks for testing processing speed. For example, Four-Choice Reaction Time task requires participants to click the key (“1”, “2”, “3”, and “4”) to a matched presented number on the screen as fast as possible (Brown et al., 2012), which requires speed and accuracy. However, the Trail Making task only records the speed, which likely requires less concern from participants about accuracy. The current study suggests that musicians’ better working memory may not be due to the faster processing speed when they do not consider the speed-accuracy trade-off.

Between group analyses of formal musical training and ability to read musical notation on mini-PROMS and its subtests indicated validity, with the exception of the Tempo subtest. In other words, my validity analyses support the examination from Zentner and Strauss (2017) for mini-PROMS, melody, tuning, and accent, but not for tempo. A possible explanation for the lack of validity support for mini-PROMS and Tempo in this study is the small sample size (34 participants). Zentner and Strauss (2017) recruited 150 participants. In my study, the effect sizes for melody, tuning, and accent were all large, whereas the effect sizes for tempo were medium. Between groups analyses on the effects of formal musical training and the ability to read western musical notation on Tempo would likely be supported with a larger sample size.

Strengths and Limitations

Previous literature has been inconsistent in finding advantages in musical training regarding far transfer skills (Mehr, 2015; Sala & Gobet, 2017b). My study addresses several reasons for these inconsistencies. First, visual-spatial working memory, verbal working memory, and processing speed are cognitive skills that are logically related to musical training. D’Souza and Wiseheat (2018), used non-verbal intelligence to explore the benefit of musical training on cognition and did not establish a correlation. However, non-verbal intelligence may be unrelated to musical training and overlap less as a far transfer skill with musical training compared to other cognitive skills. I propose that previous studies used skills that are not necessarily related to musical training.

Second, my study used Mini-PROMS, a well-known musical skill test with appropriate reliability and validity to standardize the term “musicians”, rather than simply defining musicians as music-majored undergraduate students (Schellberg, 2006). Previous literature had different standards of musicians, which may threaten the reliability. For example, some used undergraduate music majors (Schellberg, 2006), whereas some focused on how much time musicians spent on practice (Mehr, 2015). In my study, undergraduate students rarely identified as being professional musicians. There should be a test for musicians to identify their expertise. The continuous measurement of music skills—Mini-PROMS—as opposed to a dichotomous comparison—musicians versus non-musicians—could also improve the ability to find effects. Moreover, the sub-test of Mini-PROMS helps understand that musicians have better cognitive skills not just seen in their overall music ability, but with sub-skills such as melody and accent. Studying musical skill overall as opposed to at the level of musical sub-skills may mask transfer to cognitive skills.

Third, the cognitive measurements I used were all found in the previous music cognition research (Bugos & Mostafa, 2011; Lu, 2012; Vuvan et al., 2020). The reason that previous literature did not find a benefit of musical training can be that the method they used was not sensitive. For instance, in longitudinal studies, the time of musical training that researchers monitored might be too short to find significant improvement (D'Souza et al., 2018). Moreover, intelligence tests may not be appropriate measures of musical training because they tested all domains of cognition development rather than sub-domain cognitive processing (Hyde et al., 2009).

However, my study was not without limitations. First, due to technical problems, I had different sample sizes for different comparisons due to pairwise deletion, which made the sample size smaller than expected in some correlations. Especially, the limited small sample size of t-tests involving low versus high mini-PROMS and mediation analysis may cause the possibility of low statistical power. Second, due to COVID, some of the experiment was conducted remotely. It was harder to manipulate than in-person because of the technology problems, such as the appearance of N-back task, could not be solved immediately when participants sought help. Third, our study only recruited six music majors, which may not address the span of differences between musicians and non-musicians. This restriction of range may have reduced the ability to observe significant correlations in this study. Future studies should concentrate on recruiting more music majors and professional musicians to maximize effect sizes and to see if more cognitive domains are associated with musical skill. In addition, it may be important to study the differences between different types of training to target whether participants can read western musical notation (e.g., piano, voice) or not (e.g., ukulele, drums). It is recommended that future studies recruit from different studios to examine the correlation of different types of musical training with different cognitive domains. It is also recommended that future studies expand the sample size and operate in a consistent modality (e.g., entirely in person) across the whole experiment.

Conclusion and Study Implications

To conclude, some highly developed music skills are specifically correlated with better cognitive skills: melody and visual-spatial working memory, verbal working memory, and processing speed; and accent and processing speed. It can be indicated that the auditory, visual, and motor aspects of musical training may be associated with improved working memory capacity and faster information processing speed. The current study suggests that using continuous measurements like Mini-PROMS is effective for standardizing “musicians”, and their overall music skills and sub-music skills should all be studied in research on music and cognition. Future studies are recommended looking at the potential correlation between musical training or trained musical sub-skills with other far-transferred cognitive skills, and compare the differences between different ages that musicians started their training to find out the potential maximum of the benefit of musical training on cognitive development.

References

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612–637. http://dx.doi.org/10.1037/0033-2909.128.4.612

Benz, S., Sellaro, R., Hommel, B., & Colzato, L. S. (2016). Music makes the world go round: the impact of musical training on non-musical cognitive functions-A review. *Frontiers in Psychology*, *6*, Article 2023. https://doi.org/10.3389/fpsyg.2015.02023

Bugos, J., Perlstein, W., McCrae, C., Brophy, T., & Bedenbaugh, P. (2007). Individualized piano instruction enhances executive functioning and working memory in older adults. *Aging & Mental Health*, *11*(4), 464–471. http://dx.doi.prg/10.1080/13607860601086504

Bugos, J., & Mostafa, W. (2011). Musical training enhances information processing speed. *Bulletin of the Council for Research in Music Education,187*(187), 7–18. http://dx.doi.prg/10.2307/41162320

Bull, R., & Johnston, R. S. (1997). Children's arithmetic difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology*, *65*(1), 1–24. http://dx.doi.prg/10.1006/jecp.1996.2358

Brown, L. A., Brockmole, J. R., Gow, A. J., & Deary, I. J. (2012). Processing speed and visuo-spatial executive function predict visual working memory ability in older adults. *Experimental Aging Research, 38*(1), 1–19. http://dx.doi.org/10.1080/0361073X.2012.636722

Carey, D., Rosen, S., Krishnan, S., Pearce, M. T., Shepherd, A., Aydelott, J., & Dick, F. (2015). Generality and specificity in the effects of musical expertise on perception and cognition. *Cognition, 137,* 81–105. http://dx.doi.org/10.1016/j.cognition.2014.12.005

Conway, A. R. A., Kane, M. J., Bunting, M. F. D., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–786. http://dx.doi.prg/10.3758/bf03196772

Corrigall, K. A., & Trainor, L. J. (2011). Associations between length of music training and reading skills in children. *Music Perception*, *29*(2), 147–155. https://doi.org/10.1525/mp.2011.29.2.147

D'Souza, A., & Wiseheart, M. (2018). Cognitive effects of music and dance training in children. *Archives of Scientific Psychology*, *6*(1), 178–192. http://dx.doi.org/10.1037/arc0000048

Draheim, C., Harrison, T. L., Embretson, S. E., & Engle, R. W. (2018). What item response theory can tell us about the complex span tasks. *Psychological Assessment*, *30*(1), 116–129. https://doi.org/10.1037/pas0000444

Franklin, M. S., Moore, K. S., Yip, C., Jonides, J., Rattray, K., & Moher, J. (2008). The effects of musical training on verbal memory. *Psychology of Music*, *36*(3), 353–365. http://dx.doi.org/2048/10.1177/0305735607086044

Felder, V., Jönsson-Steiner, E., Eulitz, C., &Lahiri, A. (2009). Asymmetric processing of lexical tonal contrast in Swedish. *Attention, Perception, & Psychophysics*, *71*, 1890–1899. https://doi.org/10.3758/APP.71.8.1890

Fry, A. F., & Hale, S. (2000). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology. 54*, 1–34. http://dx.doi.org/10.1016/S0301-0511(00)00051-X

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *Journal of Neuroscience*, *23*(27) 9240–9245. http://dx.doi.org/ 10.1523/JNEUROSCI.23-27-09240.2003

George, E. M., & Coch, D. (2011). Music training and working memory: An ERP study. *Neuropsychologia, 49*(5), 1083–1094. http://dx.doi.org/10.1016/j.neuropsychologia.2011.02.001

Hannon, E. E., & Trainor, L. J. (2007). Music acquisition: Effects of enculturation and formal training on development. *Trends in Cognitive Sciences*, *11*(11), 466–472. http://dx.doi.org/10.1016/j.tics.2007.08.008

Hayward, C. M., & Gromko, J. E. (2009). Relationships among music sight-reading and technical proficiency, spatial visualization, and aural discrimination. *Journal of Research in Music Education*, *57*(1), 26–36. https://doi.org/10.1177/0022429409332677

Hetland, L. (2000). Learning to make music enhances spatial reasoning. *Journal of Aesthetic Education*, *34*(3), 179–238. http://dx.doi.org/10.2307/3333643

Hyde, K., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A., & Schlaug, G. (2009). Musical training shapes structural brain development. *The Journal of Neuroscience*, *29*(10), 3019–3025. http://dx.doi.org/10.1523/JNEUROSCI.5118-08.2009

Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guiford Press.

Jentschke, S., & Koelsch, S. (2009). Musical training modulates the development of syntax processing in children. *NeuroImage*, *47*(2), 735–744. http://dx.doi.org/10.1016/j.neuroimage.2009.04.090

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin, 109*(3), 490–501. https://doi.org/10.1037/0033-2909.109.3.490

Law, L. N. C., & Zentner, M. (2012). Assessing musical abilities objectively: Construction and validation of the profile of music perception skills. *PLOS ONE, 7*(12), Article e52508. http://dx.doi.org/10.1371/journal.pone.0052508

Lee, Y., Lu, M., & Ko, H. (2007). Effects of skill training on working memory capacity. *Learning and Instruction*, *17*(3), 336–344. http://dx.doi.org/10.1016/j.learninstruc.2007.02.010

Lehnert, G., & Zimmer, H. (2006). Auditory and visual spatial working memory. *Memory & Cognition*, *34*(5), 1080–1090. http://dx.doi.org/10.3758/bf03193254

Levitin, D. (2006). *This is your brain on music: The science of a human obsession*. Dutton/Penguin Books.

Levitin, D., Grahm, J., & London, J. (2018). The psychology of music: Rhythm and movement. *Annual Review of Psychology, 69*, 51–75. http://dx.doi.org10.1146/annurev-psych-122216-011740

Lu, C. (2012). *The effect of musical training on verbal and tonal working memory*. [Doctoral Dissertation, Wayne State University]. Wayne State University Digital Archive. https://digitalcommons.wayne.edu/cgi/viewcontent.cgi?article=1547&context=oa_dissertations

Magnuson, M.E., Thompson, G.J., …, Schwarb, H. (2015). Errors on interrupter tasks presented during spatial and verbal working memory performance are linearly linked to large-scale functional network connectivity in high temporal resolution resting state fMRI. *Brain Imaging and Behavior*, *9***,** 854–867. https://doi.org/10.1007/s11682-014-9347-3

Mehr, S. A. (2015). Miscommunication of science: Music cognition research in the popular press. *Frontiers in Psychology*, *6*, Article 988. http://dx.doi.org/10.3389/fpsyg.2015.00988

Moreno, S., & Besson, M. (2006). Musical training and language-related brain electrical activity in children. *Psychophysiology, 43*(3), 287–291. http://dx.doi.org/10.1111/j.1469-8986.2006.00401.x

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science, 22*(11), 1425–1433. http://dx.doi.org/10.1177/0956797611416999

Nutley, S. B., Darki, F., & Klingberg, T. (2014). Music practice is associated with development of working memory during childhood and adolescence. *Frontiers in Human Neuroscience, 7*(9), 1662–5161. http://dx.doi.org/10.3389/fnhum.2013.00926

Ontario Ministry of Education. (2009). *The Ontario curriculum grades 1–8: The Arts*. http://www.edu.gov.on.ca/eng/curriculum/elementary/arts18b09curr.pdf

Petschke, H., Lindner, K., & Rappelsberger, P. (1988). The EEG: An adequate method to concretize brain process elicited by music. *Music Perception, 6*(2), 133–160. https://doi.org/10.2307/40285422

Pretto, M., & James, C. (2015). Principles of parsimony: fMRI Correlates of beat-based versus duration-based sensorimotor synchronization. *Psychomusicology, 25*(4), 380–391. http://dx.doi.org/10.1037/pmu0000122

Porflitt, F., & Rosas-Díaz, R. (2020a). Behind the scene: Cognitive benefits of playing a musical instrument. Executive functions, processing speed, fluid intelligence and divided attention. *Studies in Psychology, 40*(2), 464–490. https://doi.org/10.1080/02109395.2019.1601474

Porflitt, F., & Rosas, R. (2020b). Core music elements: Rhythmic, melodic and harmonic musicians show differences in cognitive performance. *Studies in Psychology, 41*(3), 532–562. http://dx.doi.org.libpdb.d.umn.edu:2048/10.1080/02109395.2020.1795493

Ragland, J. D., Turetsky, B. I., Gur, R. C., Gunning-Dixon, F., Turner, T., Schroeder, L., Chan, R., & Gur, R. E. (2002). Working memory for complex figures: An fMRI comparison of letter and fractal n-back tasks. *Neuropsychology*, *16*(3), 370–379. https://doi.org/10.1037/0894-4105.16.3.370

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment, 28*(3), 164–171. http://dx.doi.org/10.1027/1015-5759/a000123

Reitan, R. M. (1955). The relation of the trail making test to organic brain damage. *Journal of Consulting Psychology, 19*(5), 393–394. https://doi.org/10.1037/h0044509

Roden, I., Könen, T., Bongard, S., Frankenberg, E., Friedrich, E. K., & Kreutz, G. (2014). Effects of music training on attention, processing speed and cognitive music abilities—Findings from a longitudinal study. *Applied Cognitive Psychology, 28*(4), 545–557. http://dx.doi.org/10.1002/acp.3034

Royer, J. M., Mestre, J. P., & Dufresne, R. (2005). Introduction: Framing the transfer problem. In J. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. vii–xxvii). Information Age Publishing.

Saarikivi, K. A., Huotilainen, M., Tervaniemi, M., & Putkinen, V. (2019). Selectively enhanced development of working memory in musically trained children and adolescents. *Frontiers in Integrative Neuroscience, 13*, Article 62. http://dx.doi.org/10.3389/fnint.2019.00062

Sala, G., & Gobet, F. (2017). When the music's over: Does music skill training transfer to children's and young adolescents' cognitive and academic skills? A meta-analysis. *Educational Psychology Review, 20,* 55–67. http://dx.doi.org/10.1016/j.edurev.2016.11.005

Sares, A. G., Foster, N. E. V., Allen, K., & Hyde, K. L. (2018). Pitch and time processing in speech and tones: The effects of musical training and attention. *Journal of Speech, Language, and Hearing Research, 61*(3), 496–509. http://dx.doi.org/10.1044/2017_JSLHR-S-17-0207

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology, 98*(2), 457–468. http://dx.doi.org/10.1037/0022-0663.98.2.457

Schellenberg, E. G. (2016). Music training and nonmusical abilities. In S. Hallam, I. Cross, & M. Thaut (Eds.), *The Oxford handbook of music psychology* (2nd ed., pp. 415–429). Oxford University Press.

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill*. Harvard University Press.

Slevc, L. R., Davey, N., Buschkuehl, M., & Jaeggi, S. (2016). Tuning the mind: Exploring the connections between musical ability and executive functions. *Cognition*, *152*, 199–211. https://doi.org/10.1016/j.cognition.2016.03.017

Talamini, F., Carretti, B., & Grassi, M. (2016). The working memory of musicians and nonmusicians. *Music Perception, 34*. 183-191. https://doi.org/ 10.1525/MP.2016.34.2.183.

Tan, S. L., Pfordresher, P., & Harré, R. (2010). *Psychology of music: From sound to significance*. Psychology Press.

Vuvan, D. T., Simon, E., Baker, D. J., Monzingo, E., & Elliott, E. M. (2020). Musical training mediates the relation between working memory capacity and preference for musical complexity. *Memory & Cognition, 48*(2), 972–981. https://doi.org/10.3758/s13421-020-01031-7

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain plays music: Auditory–motor interactions in music perception and production. *Nature Reviews Neuroscience, 8*(7), 547–58. https://doi.org/10.1038/nrn2152

Zentner, M., & Strauss, H. (2017). Assessing musical ability quickly and objectively: Development and validation of the Short‐PROMS and the Mini‐PROMS. *Annals of the New York Academic of Sciences, 1400*(1), 33–45. https://doi.org/10.1111/nyas.13410

Appendix A

Demographic Survey with Musical Training Background

Do you play musical instrument(s) or sing? Yes No

Do you have any musical non-academic qualification(s) or music award(s)? Yes No

How many years have you studied playing instrument or sing? ____

Do you still play the instrument or sing? Yes No

How often do you practice the instrument or sing on your own weekly? ___

Do you have a university degree in music? Yes No

What is your area in music? ___

Do you have perfect/absolute pitch? (an ability of a person to identify or recreate a musical note without the benefit of an external reference)?

Yes No

Can you read western musical notation? Yes No

How often do you listen to music?
Occasionally
One-two days/ week
Two-three days/ week
Three-four days/ week
Four-five days/ week
Five-six days/ week
Everyday

Are you involved actively in professional listening activities? (e.g. Conducting, Sound Engineering, Piano Tuning, Performing, DJ-ing, Music Perception Research and others)

Yes No

Would you consider yourself as a(n)... Non-musician

Music loving non-musician

Amateur Musician

Semi-professional musician

Professional musician

Are any members of your family musicians?

No Yes, amateur musicians Yes, professional musicians

Appendix B

Mediation Models and Coefficients

	Consequent					
	M (PS)			Y (SSPAN)		
Antecedent	*Coeff.*	*SE*	*p*	*Coeff.*	*SE*	*p*
X (PROMS)	*–1581.65*	*674.04*	*.03*	*–.78*	*.36*	*.83*
M (PS)	—	—	—	*–.00*	*0.00*	*.15*
Constant	*118957.58*	*15246.46*	*<.001*	*34.85*	*13.08*	*.01*
	$R^2 = .164$			$R^2 = .082$		
	F(1, 28) = 5.506, p =.03			*F(2, 27) = 1.200, p = .32*		
	M (PS)			*Y (SR_STC)*		
X (PROMS)	*–1581.65*	*674.04*	*.03*	*.001*	*.42*	*.96*
M (PS)	—	—	—	*<.001*	*<.001*	*.23*
Constant	*118957.58*	*15246.46*	*<.001*	*2.05*	*1.53*	*.19*
	$R^2 = .164$			$R^2= .063$		
	F(1, 28) = 5.506, p =.03			*F(2, 27) = .900 p = .42*		
	M (PS)			*Y (Nback)*		
X (PROMS)	*–1759.96*	*764.35*	*.03*	*.04*	*.04*	*.24*
M (PS)	—	—	—	*<.001*	*<.001*	*.25*
Constant	*122122.26*	*17093.80*	*<.001*	*2.76*	*1.31*	*.045*
	$R^2 = .175$			$R^2 = .171$		
	F(1, 25) = 5.30, p = .03			*F(2, 24) = 2.47, p =.11*		
	M (PS)			*Y (Nback–2)*		
X (PROMS)	*–1759.96*	*764.35*	*.03*	*.07*	*.07*	*.34*
M (PS)	–	–	–	*<.001*	*<.001*	*.83*
Constant	*122122.26*	*17093.80*	*<.001*	*1.88*	*2.48*	*.46*

	$R^2 = .175$			$R^2 = .055$		
	F(1, 25) = 5.30, p = .03			F(2, 24) = .70, p =.51		
	M (PS)			Y (Nback–3)		
X (PROMS)	–1759.96	764.35	.03	.03	.05	.54
M (PS)	—	—	—	<.001	<.001	.05
Constant	122122.26	17093.80	<.001	3.31	1.78	.07
	$R^2 = .175$			$R^2 = .230$		
	F(1, 25) = 5.31, p = .03			F(2, 24) = 3.28, p = .04		
	M (PS)			Y (SSPAN)		
X (Melody)	–3928.64	1967.23	.05	1.19	.96	.23
M(PS)	—	—	—	–0.0001	<.001	.30
Constant	107823.16	13378.17	<.001	22.03	10.93	.05
	$R^2 = .125$			$R^2 = .129$		
	F(1, 28) = 3.99, p = .06			F(2, 27) = 2.00, p =.15		
	M (PS)			Y (SSPAN)		
X (Tuning)	–3754.22	2107.29	.09	–.22	1.03	.83
M(PS)	—	—	—	–0.0001	<.001	.14
Constant	103133.06	11248.21	<.001	34.08	10.45	.003
	$R^2 = .102$			$R^2 = .082$		
	F(1, 28) = 3.17, p = .09			F(2, 27) = 1.20, p =.32		
	M (PS)			Y (SSPAN)		
X (Accent)	–4577.96	2074.82	.04	–.79	1.06	.47
M(PS)	—	—	—	–.0002	<.001	.10
Constant	110399.82	12398.36	<.001	39.11	11.47	.002
	$R^2 = .148$			$R^2 = .098$		
	F(1, 28) = 4.87, p = .04			F(2, 27) = 1.47, p =.25		

	M (PS)			*Y (SSPAN)*		
X (Tempo)	*–2330.96*	*2282.03*	*.32*	*–1.00*	*1.03*	*.34*
M(PS)	—	—	—	*–.0001*	*<.001*	*.10*
Constant	*95889.57*	*12175.57*	*<.001*	*38.88*	*9.63*	*<.001*
	$R^2 = .036$			$R^2 = .112$		
	F(1, 28) = 1.04, p = .32			*F(2, 27) = 1.69, p =.20*		
	M (PS)			*Y (SR_STC)*		
X (Melody)	*–3928.64*	*1967.23*	*.06*	*–.20*	*.11*	*.08*
M(PS)	—	—	—	*<.001*	*<.001*	*.50*
Constant	*107823.16*	*12378.17*	*<.001*	*3.82*	*1.24*	*.004*
	$R^2 = .125$			$R^2 = .164$		
	F(1, 28) = 3.99, p = .06			*F(2, 27) = 2.65, p =.09*		
	M (PS)			*Y (SR_STC)*		
X (Tuning)	*–3754.22*	*2107.29*	*.09*	*.03*	*.12c*	*.83*
M(PS)	—	—	—	*<.001*	*<.001*	*.19*
Constant	*103133.06*	*11248.21*	*<.001*	*1.89*	*1.22*	*.13*
	$R^2 = .102$			$R^2 = .064$		
	F(1, 28) = 3.17, p = .09			*F(2, 27) = .92, p =.41*		
	M (PS)			*Y (SR_STC)*		
X (Accent)	*–4577.96*	*2074.82*	*.04*	*.05*	*.13*	*.70*
M(PS)	—	—	—	*<.001*	*<.001*	*.17*
Constant	*110399.82*	*12398.36*	*<.001*	*1.67*	*1.35*	*.23*
	$R^2 = .148$			$R^2 = .068$		
	F(1, 28) = 4.87, p = .04			*F(2, 27) = .98, p = .39*		
	M (PS)			*Y (SR_STC)*		
X (Tempo)	*–2330.96*	*2282.03*	*.32*	*.16*	*.12*	*.18*

M(PS)	—	—	—	<.001	<.001	.12
Constant	95889.57	12175.57	<.001	1.04	1.11	.36
		$R^2 = .036$			$R^2 = .125$	
		F(1, 28) = 1.04, p = .32			F(2, 27) = .19, p = .17	
		M (PS)			Y (Nback)	
X (Melody)	–4043.99	2179.13	.08	.18	.10	.08
M(PS)	—	—	—	<.001	<.001	.25
Constant	107830.11	13547.17	<.001	2.62	1.04	.02
		$R^2 = .121$			$R^2 = .229$	
		F(1, 25) = 3.44, p = .08			F(2, 24) = 3.57, p =.04	
		M (PS)			Y (Nback)	
X (Tuning)	–4426.80	2721.44	.12	.04	.12	.72
M(PS)	—	—	—	<.001	<.001	.12
Constant	105454.25	13928.45	<.001	3.80	1.09	.002
		$R^2 = .096$			$R^2 = .125$	
		F(1, 25) = 2.64, p = .12			F(2, 24) = 1.71, p =.20	
		M (PS)			Y (Nback)	
X (Accent)	–4205.79	2199.41	.07	.08	.10	.42
M(PS)	—	—	—	<.001	<.001	.17
Constant	108333.59	13425.29	<.001	3.40	1.10	.005
		$R^2 = .128$			$R^2 = .144$	
		F(1, 25) = 3.66, p = .07			F(2, 24) = 2.02, p =.15	
		M (PS)			Y (Nback)	
X (Tempo)	–2914.97	2480.02	.25	.03	.11	.81
M(PS)	–	–	–	<.001	<.001	.10
Constant	98410.92	13155.56	<.001	3.93	.10	<.001

	R^2 = .052			*R^2 = .122*		
	F(1, 25) = 1.38, p = .25			*F(2, 24) = 1.67, p =.20*		
	M (PS)			*Y (Nback–2)*		
X (Melody)	*–4043.99*	*2179.13*	*.08*	*.30*	*.18*	*.12*
M(PS)	—	—	—	*<.001*	*<.001*	*.93*
Constant	*107830.11*	*13547.17*	*<.001*	*1.40*	*1.99*	*.49*
	R^2 = .121			*R^2 = .117*		
	F(1, 25) = 3.44, p = .08			*F(1, 25) = 1.58, p = .23*		
	M (PS)			*Y (Nback–2)*		
X (Tuning)	*–4426.80*	*2721.44*	*.12*	*.20*	*.23*	*.39*
M(PS)	—	—	—	*<.001*	*<.001*	*.71*
Constant	*105454.25*	*13928.45*	*<.001*	*2.56*	*2.02*	*.22*
	R^2 = .096			*R^2 = .049*		
	F(1, 25) = 2.64, p = .12			*F(2, 24) = .62, p =.55*		
	M (PS)			*Y (Nback–2)*		
X (Accent)	*–4205.79*	*2199.41*	*.07*	*.04*	*.19*	*.84*
M(PS)	—	—	—	*<.001*	*<.001*	*.58*
Constant	*108333.59*	*13425.29*	*<.001*	*3.60*	*2.10*	*.10*
	R^2 = .128			*R^2 = .020*		
	F(1, 25) = 3.66, p = .07			*F(2, 24) = .24, p = .79*		
	M (PS)			*Y (Nback–2)*		
X (Tempo)	*–2914.97*	*2480.02*	*.25*	*–.01*	*.20*	*.96*
M(PS)	—	—	—	*<.001*	*<.001*	*.51*
Constant	*98410.92*	*13155.56*	*<.001*	*3.99*	*1.86*	*.04*
	R^2 = .052			*R^2 = .018*		
	F(1, 25) = 1.38, p = .25			*F(2, 24) = .22, p =.80*		

	M (PS)			Y (Nback–3)		
X (Melody)	–4043.99	2179.13	.08	.13	.13	.34
M(PS)	—	—	—	<.001	<.001	.04
Constant	107830.11	13547.17	<.001	3.15	1.46	.04
	$R^2 = .121$			$R^2 = .247$		
	F(1, 25) = 3.44, p = .08			F(2, 24) = 3.92, p =.03		
	M (PS)			Y (Nback–3)		
X (Tuning)	–4426.80	2721.44	.12	–.07	.16	.68
M(PS)	—	—	—	<.001	<.001	.02
Constant	105454.25	13928.45	<.001	4.72	1.45	.003
	$R^2 = .096$			$R^2 = .223$		
	F(1, 25) = 2.64, p = .12			F(2, 24) = 3.45, p =.05		
	M (PS)			Y (Nback–3)		
X (Accent)	–4205.79	2199.41	.07	.04	.14	.78
M(PS)	—	—	—	<.001	<.001	.03
Constant	10833.59	13425.29	<.001	3.92	1.49	.01
	$R^2 = .128$			$R^2 = .220$		
	F(1, 25) = 3.66, p = .07			F(2, 24) = 3.38, p =.05		
	M (PS)			Y (Nback–3)		
X (Tempo)	–2914.97	2480.02	.25	.12	.14	.40
M(PS)	—	—	—	<.001	<.001	.03
Constant	98410.92	13155.56	<.001	3.45	1.31	.01
	$R^2 = .052$			$R^2 = .241$		
	F(1, 25) = 1.38, p = .25			F(2, 24) = 3.80, p =.04		

Note. The number of participants in models with VS and SR_STC = 31. The number of participants in models with Nback, Nback-2, and Nback-3 = 27.PROMS = the score of Mini–

PROMS. SSPAN = number of correctly recalled squares in each perfectly recalled set; a measure of visual spatial working memory. STC = total number of correctly recalled squares; a measure of the capacity of visual spatial working memory. SR_STC = Reverse scored and square root of STC. Nback = d-prime for all trials; Nback-2 = d-prime for trial n = 2; Nback-3 = d-prime for trial n = 3; measures of verbal working memory. Trail making = time (ms) to complete Trails A and B; a measure of processing speed.