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Cross-sectional study on the relationship between music training and working memory in adults

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Abstract

Learning to play musical instruments has been shown to enhance a wide variety of cognitive domains. The present study investigated the specific aspects of working memory (WM) that differed between adult musicians and non-musicians. Twenty-four musicians and 30 non-musicians matched for age, gender, years of formal education, and verbal intelligence performed several WM tasks. A multivariate analysis of covariance, wherein family income was controlled, revealed that musicians outperformed non-musicians in tasks related to visual–motor coordination, visual scanning ability, visual processing speed, and spatial memory. However, no significant differences were found in phonological and visual memory capacity. This study supports the view that music training is associated to specific (and not general) WM skills.

Key words: executive function, music training, phonological memory, spatial memory, visual memory, working memory

Professional music training of playing musical instruments or vocal training allows musicians to be trained in different cognitive abilities (Milovanov & Tervaniemi, 2011). Studies have found formal music training to be beneficial for a wide variety of cognitive abilities including attention span (Patston, Kirk, Rolfe, Corballis, & Tippett, 2007), intelligence quotient (IQ; Schellenberg, 2004, 2006), sight reading (McPherson, 1995), and auditory (Kraus & Chandrasekaran, 2010), motor (Amunts et al., 1997), verbal (Chan, Ho, & Cheung, 1998), and visuospatial abilities (Brochard, Dufour, & Després, 2004).

The present study links these cognitive benefits to enhanced working memory (WM) performance. WM has been defined as 'a limited-capacity system for temporary storage and manipulation of information for complex tasks such as comprehension, learning, and reasoning' (Goldstein, 2008, p. 410).

According to Lee, Lu, and Ko (2007), WM plays a significant role in carrying out complex cognitive tasks. George and Coch (2011) proposed that WM might play a role in mediating the cognitive benefits in musicians. Thus, the present study focuses on which aspects of the WM musicians might benefit from music training.

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WM, music training, and transfer effects

The WM model by Baddeley (2000) was used in this study as it serves as a useful model that provides temporary storage and manipulation of information, and is an essential infrastructure for understanding a wide range of cognitive skills such as attention, language comprehension, vocabulary acquisition, reading, memorising, reasoning, and orientation (Baddeley, 1992; Williamson, Baddeley, & Hitch, 2010).

WM is multifaceted and comprises of four domains: the central executive, phonological loop, visuospatial sketchpad, and the episodic buffer as seen in Fig. 1.

The central executive is responsible for attentional control. It allocates attentional resources to the other WM components (Baddeley, 2003). Transfer effects from music training to executive functions are evidenced in studies that show that musicians are better than non-musicians at sustaining attention and cognitive control (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Degé, Kubicek, & Schwarzer, 2011; George & Coch, 2011; Kraus & Chandrasekaran, 2010; Moreno et al., 2011). Typical measures tapping into executive functions include tasks on perceptual skills, perceptual speed, and attentional control. The benefits of music training on executive functions have been consistently observed in children, adults, and elders as well as professional and amateur musicians. One exception is Lee et al. (2007), who found benefits of music training on executive functions in children, but not in adults.

The visuospatial sketchpad stores and manipulates visuospatial information (Baddeley & Della Sala, 1996). Transfer effects from formal music training to visuospatial

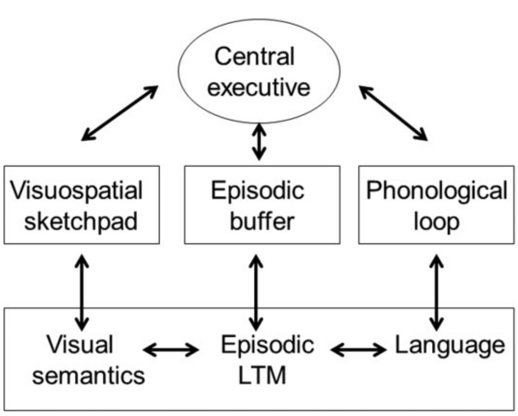

Figure 1 Working memory model (Baddeley, 2000). Reproduced with permission.

memory are expected as the musical notations studied by musicians are spatial (Hetland, 2000; Stewart et al., 2003). Also, musicians need to decode visually presented musical notations into sequential finger movements and memorise long musical notations (Gaser & Schlaug, 2003; Kopiez, Weihs, Ligges, & Lee, 2006). However, findings of music training effects on visuospatial WM have not been unanimous. Some authors (e.g., Brandler & Rammsayer, 2003; Chan et al., 1998; Helmbold, Rammsayer, & Altenmüller, 2005; Ho, Cheung, & Chan, 2003) have not found differences between musicians and non-musicians regarding visuospatial abilities. In contrast, other researchers (e.g., George & Coch, 2011; Jakobson, Lewycky, Kilgour, & Stoesz, 2008; Sluming, Brooks, Howard, Downes, & Roberts, 2007) have found enhanced visuospatial memory performance in musicians. Contradictory findings have been observed for studies with children (e.g., Ho et al., 2003; Lee et al., 2007; Roden, Grube, Bongard, & Kreutz, 2014) and adults (e.g., Chan et al., 1998; George & Coch, 2011; Lee et al., 2007) as well as professional (e.g., Helmbold et al., 2005; Sluming et al., 2007) and non-professional musicians (e.g., Chan et al., 1998; Jakobson et al., 2008). Tasks that involve visuospatial memory require participants to memorise objects, memorise and reproduce figures, locate memorised objects in the space, produce mental rotation of objects, and so on. Overall, it is yet unclear whether musicians show visuospatial WM advantage.

The phonological loop is implicated in the storage and rehearsal of verbal information. Yet it is unclear whether the phonological loop processes music, too. Berz (1995) proposed a music memory loop because memory for music is less susceptible to forgetting than memory for words. However, short-term memory for both music and verbal information show recency effects, and recall declines with articulatory suppression, acoustic similarity, and sequence length (Berz, 1995; Williamson et al., 2010). Williamson et al. (2010) suggested the possibility of a phonological store and a tonal store with an articulatory rehearsal process common to both. In general, most studies have found a positive association between music training and performance in phonological memory tasks such as memorisation of lists of words and non-words, the forward digit span, or vocabulary tests (e.g., Brandler & Rammsayer, 2003; Bugos et al., 2007; Chan et al., 1998; George & Coch, 2011; Ho et al., 2003; Jakobson et al., 2008; Lee et al., 2007; Roden et al., 2014). One exception is Helmbold et al. (2005), who found no differences between musicians and non-musicians in their ability to recall lists of words. Verbal and phonological memory tasks measure auditory memory capacity, articulatory rehearsal, and the memorisation capability of new sound strings. Franklin et al. (2008) explained that enhanced phonological WM in musicians is associated with the use of increased rehearsal mechanisms allowing for better storage of verbal information than non-musicians.

Finally, the episodic buffer is a component that integrates and stores information between the phonological loop, visuospatial sketchpad, and information from long-term memory (LTM), which is depicted in the lower box of Fig. 1. LTM is the system wherein long-term knowledge is accumulated (Baddeley, 2000). Memory for visuospatial information is facilitated by knowledge stored in the LTM (Chase & Simon, 1973). Similarly, there appears to be a positive association between vocabulary and phonological memory (Masoura & Gathercole, 2005). Ericsson and Kintsch (1995) indicated that expertise promotes a larger WM capacity only for information associated with the field of expertise (e.g., the long-term WM model; Ericsson & Kintsch, 1995). These types of models are domain specific. In the context of music, it predicts that musicians excel in WM tasks that require cognitive processes similar to those practised through music training. For example, music training promotes auditory imagery (Bishop, Bailes, & Dean, 2013; Brodsky, Henik, Rubinstein, & Zorman, 2003), and auditory imagery skills are associated with the capacity to mentally maintain and manipulate music and common sounds as well as to suppress irrelevant information (Aleman, Nieuwenstein, Böcker, & De Haan, 2000; Brown & Palmer, 2013). Music sight reading, in particular, has been associated with the capacity to rapidly scan visual information, kinaesthetic abilities, and mentally transforming images of spatial patterns (Hayward & Gromko, 2009). Thus, if the cognitive benefits associated with music training are domain specific, musicians should outperform non-musicians in WM tasks that require psychomotor speed, hand–eye coordination, spatial processing, mental manipulation of information, and inhibitory control of irrelevant stimuli because these are processes practised during music learning. In contrast, if the beneficial effects of music training are domain general, musicians should outperform non-musicians in all WM tasks.

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Table 1 Mean and standard deviations of the participants' characteristics

	Musicians		Non-musicians			
	M	*SD*	*M*	*SD*	*F*	*p*
Age	22.50	4.93	22.67	2.93	.02	.88
Education (years)	14.75	2.85	15.43	2.25	.97	.33
Verbal IQ	106.42	5.64	106.20	5.90	.02	.89
Family income	124,992	127,092	68,409	30,630	5.57	.02[a]

Note. *M* = mean; *SD* = standard deviation.
[a]Musicians and non-musicians differed regarding family income. This variable was used as a covariate in the main analysis.

This study aimed to reach a better understanding of what musical training may deliver by way of improved cognitive functioning. Specifically, this study aimed to determine if music training affects all or some components of WM and, if only some, which ones. Based on the evidence from previous studies, it was hypothesised that musicians outperform non-musicians in WM tasks.

METHOD

Participants

Sixty-nine students from James Cook University (Singapore) studying undergraduate courses of psychology, business, or information technology participated for credit points or a $10 gift card. Fifteen participants were excluded because of inability to follow instructions, visual impairment, informal music training, or because they were novice musicians (between 1 and 5 years of formal music training experience).

The final sample comprised 54 participants with no hearing, reading, or attentional disabilities. The sample was divided into two groups consisting of musicians ($N = 24$) and non-musicians ($N = 30$). Musicians were defined as those with formal music training in any instrument for 5 years or more ($M = 10.38$, standard deviation (SD) = 3.81, range = 5–20). For the musician group, participants started playing their first instrument around 8 years old ($SD = 3.09$, range = 3–13). The non-musician group had received no music training. The allocation of the participants to either the musician or non-musician groups was strengthened by their results in the Advanced Measures of Music Audiation (AMMA; Gordon, 1989) test, which measures music aptitude. Previous research has found a positive and significant relationship between sight-reading ability and music aptitude (e.g., Hayward & Gromko, 2009). Therefore, we expected higher AMMA scores in musicians than non-musicians. A one-way between-groups analysis of variance was conducted to explore group differences between musicians and non-musicians on the AMMA total scores. One of the participants did not perform this task; thus, the data were treated as missing. Results revealed that musicians scored significantly higher ($M = 61.30$, $SD = 7.69$) than non-musicians ($M = 51.10$, $SD = 8.12$) on the AMMA test, $F(1, 51) = 21.53$, $p < .001$, $\eta^2_p = .30$, which helps to confirm that musicians showed more musical aptitude than non-musicians. The number of males and females in the musicians and non-musicians were similar: The musicians group was formed by 4 males and 20 females, and the non-musicians group was made by 7 males and 23 females. Moreover, musicians and non-musicians did not differ in age, years of education, and verbal IQ (obtained with the American National Adult Reading Test (AMNART); Grober & Sliwinski, 1991). Table 1 shows exact values. However, as shown in Table 1, musicians and non-musicians varied regarding family income. Thus, family income was used as a covariate in the main analysis.

Materials

Six WM tasks were programmed as an experiment using E-prime 2.0 (Psychology Software Tools, Pittsburgh, PA, USA). Eight versions of the same experiment were created to randomise the sequence of the tasks and the stimuli used in the non-word recognition task. Participants were randomly assigned to one of the eight versions and were given the opportunity to take short breaks between tasks. All the tasks were preceded by practice trials to ensure that the participants had a clear understanding of each task.

Auditory stimuli were presented through Beyerdynamic DT150 headphones (at approximately 70 dB; beyerdynamic GmbH & Co. KG, Heilbronn, Germany).

Measures of the central executive

Digit-symbol coding task

The digit-symbol coding task was adapted from the Wechsler Adult Intelligence Scale (Wechsler, 2008) coding task. The task contained a legend made of nine numbers that were each paired with a symbol (e.g., 7 was paired with Ω). Participants were required to write as quickly and accurately as possible the symbol that corresponded to each number on a response booklet containing 180 digits. The legend was visible at all times. After 2 min, a 'beep' sound was heard,

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indicating that they had to stop writing. The score for this task was calculated based on the total number of correctly written symbols.

According to Davis and Pierson (2012), the digit-symbol score is influenced by the central executive. Additionally, this task requires allocation of attentional resources, perceptual speed, and mental flexibility (Joy, Fein, & Kaplan, 2003). This task also taps into psychomotor speed, visual–motor coordination, and visual scanning ability (Wechsler, 2008).

Backward digit span task

In this task, participants heard strings of numbers from 1 to 9 and had to recall them in the reverse order. For example, if they heard '4, 9' they had to write '9, 4'. The number of digits increased in successive tests, and each test had two trials of the same length. The maximum digit span for each participant was calculated based on the total number of digits correctly recalled in the reverse order before failing two consecutive trials.

According to Hale, Hoeppner, and Fiorello (2002), in the backward digit span task, participants not only need to retain the information in their auditory span, but they require additional WM demands of transformation and manipulation of the information. According to Wechsler (2008), this task measures WM capacity. Previous studies (e.g., George & Coch, 2011; Lee et al., 2007) have also employed this task to measure executive function. Thus, in this study, the backward digit span was used to measure central executive function.

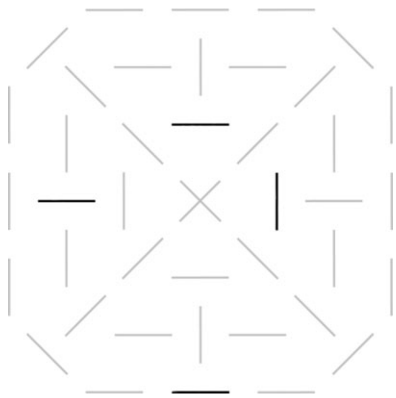

Figure 2 Example of a matrix in the static matrix span task. The critical lines are highlighted in bold in this figure. However, the lines to memorise were highlighted in red in the experiment.

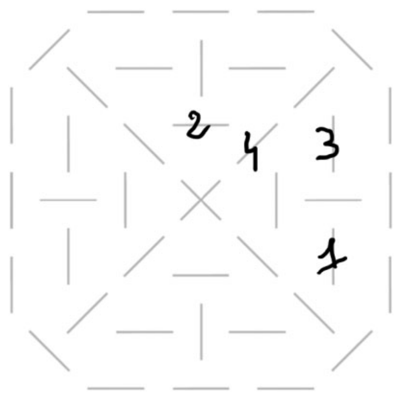

Figure 3 Example of a response for the dynamic matrix span task. In each trial, participants saw a matrix wherein red lines appeared and disappeared, and they had to indicate the lines and order of appearance.

Measures of the visuospatial sketchpad

Static matrix span task

This task was used to measure the visual span for static information. Participants were exposed to 140 × 155 mm matrices, and they had to memorise the number of the red lines that appeared on each matrix. Figure 2 shows an example of a matrix presented in the study phase.

Each matrix appeared on the screen for 10,000 ms and disappeared thereafter. Following this, a screen appeared to prompt the participants to mark down with a red pen where the lines appeared on a grey matrix printed on a response booklet.

The number of red lines that appeared on each matrix increased across tests, and each test contained two trials of the same difficulty. The score was calculated based on the maximum number of red lines recalled correctly before failing two consecutive trials.

This task aimed to measure visual memory capacity for static information.

Dynamic matrix span task

This task was used to measure visual span for storing sequence of images. In this task, participants saw a 140 × 155 mm matrix on the screen wherein different lines turned red for 2,000 ms, one at a time. Participants had to remember which lines turned red and in which order. They wrote their responses on a grey matrix printed on a response booklet. Figure 3 depicts an example of a participants' response.

Tests increased in number of red lines that appeared and disappeared, and each test was composed by two trials. The score was based on the total number of red lines recalled correctly before failing two consecutive trials.

This task was inspired by the spatial span test of the Wechsler Memory Scale III (Wechsler, 1997), which measures rote learning and spatial memory capacity.

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Measures of the phonological loop

Forward digit span task

In this task, participants were auditorally presented with a sequence of numbers, and they then had to recall and write down the numbers in the same order. For example, if they heard '4, 9' they had to write '4, 9'. Each test contained two trials of the same length, and successive trials increased in length. The maximum digit span for each participant was calculated based on the total number of digits correctly recalled in the same order before failing two consecutive trials.

This task directly examined the capacity of the phonological loop as participants only needed to hold the information in their short-term auditory memory store (Baddeley, 1992; Hale et al., 2002). Thus, the digit forward task was used to measure phonological WM.

Non-word recognition task

In this task, a total of 24 non-words were presented auditorally. This task comprised a study phase and a recognition phase. During the study phase, participants were presented with 12 non-words (e.g., /ma'tolous̯/, /so'petai̯l/), and each non-word was presented three times with an interval of 1,000 ms between repetitions and 3,000 ms between each different non-word. In the recognition phase, participants were presented with another set of recorded non-words, where half of them were identical to what was heard before (e.g., /ma'tolous̯/), and the other half were almost identical (e.g., /so'βetai̯l/), and participants had to decide as quickly and accurately as possible if the non-words that they were listening to were the same or different from what they heard previously. Responses were registered by the keyword, wherein the key 'm' meant *studied word*, and the key 'z' meant *non-studied word*.

Signal detection theory was used to score discriminability (d') at recognition. Discriminability was calculated by comparing hits (correctly recognised studied non-words) versus false alarms (falsely recognised non-studied non-words). Values below or near to zero indicate no memorisation of new phonological forms. Values above zero indicate memorisation (i.e., more hits than false alarms).

This task was created to measure phonological memory and learning capability of new phonological forms.

The AMMA test (Gordon, 1989)

AMMA measures music aptitude, and it is used to diagnose music potential. In this test, participants listened to musical patterns. Afterwards, they heard musical patterns again and had to decide whether they were the same or different. If different, they needed to identify whether they differed in tone or rhythm. According to Gordon (1989, p. 113), the AMMA retest reliability for tonal, rhythm, and total test is .89, .90 and .92, respectively.

The AMMA test was used to confirm that the musicians had better music abilities than the non-musicians.

Demographic questionnaire

Participants completed a demographic questionnaire, indicating their age, languages, gender, parental education, and family income. In addition to this, musicians had to specify their years of formal music training, hours practiced, and type of instruments played.

AMNART (Grober & Sliwinski, 1991)

AMNART was created based on the existing positive correlation between reading skill and intelligence (Grober & Sliwinski, 1991). AMNART employs the number of errors at reading irregular words (e.g., the word *aile* is pronounced /aɪl/) and years of education to estimate current verbal IQ. AMNART has successfully been cross-validated with a short version of the revised Wechsler Adult Intelligence Scale that measures verbal IQ.

Procedure

This study was conducted in a sound-attenuated lab. The study took approximately 2 hr, and it was divided into two sessions. During the first session, participants performed six WM tasks, and in the second session participants completed the music ability test (AMMA), a demographic questionnaire, and the reading test (AMNART). Participants and experimenter scheduled the second session for the same or a different day within the same week, according to the participants' availability.

RESULTS

A multivariate analysis of covariance (MANCOVA) was performed with SPSS version 20 (IBM Corporation, Armonk, NY, USA) to compare group differences in musicians and non-musicians on the six WM measures. The independent variable was music training (musicians vs non-musicians), and the dependent variables were the six WM measures. Participants' family income was used as a covariate.

Preliminary assumptions for MANCOVA (Tabachnick & Fidell, 2001) were met. The results showed a significant difference in the overall six WM measures between musicians and non-musicians, $F(6, 46) = 3.16$, $p = .01$; Wilks' lambda = .71, $\eta^2_p = .30$. However, when the results of the dependent variables were considered separately, only three variables reached statistical significance. Musicians scored

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Table 2 Mean accuracy and standard deviations for musicians and non-musicians on working memory tasks

	Musicians			Non-musicians		
Measures	*M*	*SD*	CI	*M*	*SD*	CI
Central executive						
Digit-symbol coding	62.79	15.05	56.44–69.15	53.70	11.20	49.52–57.88
Backward digit span	6.88	1.48	6.25–7.50	5.97	1.40	5.44–6.49
Visuospatial sketchpad						
Static matrix span	5.04	1.23	4.52–5.56	4.87	1.01	4.49–5.24
Dynamic matrix span	4.96	.55	4.73–5.19	4.33	.99	3.96–4.71
Phonological loop						
Forward digit span	7.79	1.59	7.12–8.46	7.13	1.43	6.60–7.67
Non-word recognition	.42	.67	.14–.70	.54	.60	.32–.76

Note. The non-word recognition task values correspond to discrimination (d') values, which measure how well participants were able to discriminate old from new non-words. CI = confidence interval; *M* = mean; *SD* = standard deviation.

significantly higher than non-musicians in the digit-symbol coding task ($F(1, 51) = 4.54$, $p = .04$, $\eta^2_p = .08$), the backward digit span task ($F(1, 51) = 4.89$, $p = .03$, $\eta^2_p = .09$), and the dynamic matrix span task ($F(1, 51) = 7.03$, $p = .01$, $\eta^2_p = .12$). However, group differences did not reach statistical significance for the static matrix span task ($F(1, 51) = .21$, $p = .65$, $\eta^2_p = .00$), forward digit span task ($F(1, 51) = 2.14$, $p = .15$, $\eta^2_p = .04$), and non-word recognition task ($F(1, 51) = 1.51$, $p = .23$, $\eta^2_p = .03$). Table 2 shows exact values.

DISCUSSION

The aim of this study was to examine WM performance between adult musicians and non-musicians. Findings showed that out of the six WM tasks, musicians significantly outperformed non-musicians only in the digit-symbol coding task and the backward digit span task (central executive function) as well as the dynamic matrix span task (visuospatial function).

Executive functions

The results showed that music training and years of music training were positively related to executive functions. Bugos et al. (2007) trained musically 60- to 85-year-old adults and found improvement for the digit-symbol task during the music training intervention as well as during the post-training interval, suggesting long-term effects of music training on executive functions. In addition, Bugos et al. showed that those musically trained performed better than a control group in the trail making test, after controlling for motor-specific skills. In the trail making test, consecutive numbers (e.g., 1, 2, 3) and consecutive letters (e.g., A, B, C) are scattered around different locations on a sheet of paper, and participants are asked to draw a line linking 1 with A, 2 with B, and so on. Both the digit-symbol coding task and the trail making test are measures of sequencing skills, visuospatial scanning and memory. Besides, Helmbold et al. (2005) found that, out of several cognitive tasks, musicians outperformed non-musicians in tasks tapping into perceptual speed (comparison of two columns of numbers or letters) and perceptual ability (detection of single elements embedded in complex objects). The perceptual tasks employed in Helmbold et al.'s study, the trail making test and digit-symbol task used in Bugos et al.'s study, and the digit-symbol task employed in the present study all measured visual perception, visual scanning ability, and visual processing speed. Moreover, those tasks involved kinaesthetic skills that have been associated with sight reading (Hayward & Gromko, 2009).

In relation to the backward digit span, we also obtained a significant effect ($p = .03$, $\eta^2_p = .09$). Results regarding the backward digit span task have been equivocal. George and Coch (2011) found a positive relationship between music training and the backward digit span in young adults, but Bugos et al. (2007) did not find differences in the backward digit span of musically trained elders and a control group, and Lee et al. (2007) found larger backward digit spans in musically trained children but not in musically trained adults (as compared with children and adults with no music training, respectively). We hypothesise that age could be an important factor. Music training enhances executive functions at early age (Steele, Bailey, Zatorre, & Penhune, 2013) and might help to maintain these functions at young adulthood (although the effects might not be so evident because of full cognitive development), but cannot counteract age-related effects when music training starts at an advanced age as in Bugos et al.'s study (60–85 years old). Bäckman and Molander (1986) hypothesised that elders show reduced capacity to inhibit irrelevant stimuli, and inhibition is a crucial aspect of the central executive.

Visuospatial functions

Previous findings showed that the relationship between music training and visuospatial memory was inconclusive. The results of this study suggested that musicians had an

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enhanced memory for dynamic information. However, no differences were found between musicians and non-musicians regarding visual memory for static information. The results agree with Gruhn, Galley, and Kluth's (2003), who found that musicians have an obvious advantage when performing cognitive tasks involving mental speed and voluntary eye control as they receive training for eye movements while reading musical notations. According to Brochard et al. (2004), music reading could have improved visual mental imagery, which explains why musicians outperform non-musicians in visuospatial tasks that require mental manipulation of visual representations. The results of the dynamic matrix task required imagery to recreate the sequence of lines that appeared and disappeared in each trial. Hayward and Gromko (2009) also found a positive relationship between musical training and the ability to mentally manipulate the image of different objects.

Interestingly, our results showed differences between musicians and non-musicians in the backward digit span (central executive task) and dynamic matrix (visuospatial task). It has been indicated that although the backward digit span might require spatial processing, the backward digit span is not a measure of spatial memory (Ramsay & Reynolds, 1995). An overlap between these two tasks is probable because the participants might have visualised the numbers in the backward digit span while these were being heard in order to facilitate recall. These results suggest that music experience seems to be associated to tasks that require retention and manipulation of visually dynamic information.

The results of the current study indicate that although musicians have similar visual memory capacity to non-musicians, musicians have an enhanced capacity for spatial memory, a skill probably acquired through the process of reading musical notations.

Unfortunately, the results of the current study cannot explain the enhanced visual memory capacity obtained by musicians for static objects (e.g., Jakobson et al., 2008) or why musicians seem not to outperform non-musicians in some spatial tasks (e.g., Brandler & Rammsayer, 2003; Helmbold et al., 2005). Thus, more research is necessary in this area.

Phonological functions

The MANCOVA did not reveal differences between musicians and non-musicians in any of the tasks related to phonological memory. These results are inconsistent with studies that have shown enhanced phonological WM performance in musicians (Brandler & Rammsayer, 2003; Chan et al., 1998; Gaser & Schlaug, 2003; George & Coch, 2011; Ho et al., 2003; Lee et al., 2007; Moreno et al., 2011; Roden et al., 2014). However, Helmbold et al. (2005) and Williamson et al. (2010) found no differences between phonological WM performance in musicians and non-musicians. Interestingly, Williamson et al. compared short-term memory for both phonological memory and tone memory, and they found that musicians outperformed non-musicians only in the tone memory task. Similarly, we found that musicians scored higher than non-musicians in the AMMA test, which required memory for rhythm and tone of short musical pieces, but not differences in verbal memory. The results suggest the possibility of separate verbal and tonal stores with articulatory rehearsal processes common to the phonological loop (Williamson et al., 2010). This hypothesis requires future research.

Limitations

The quasi-experimental nature of the study could not have ensured that the samples were identical in their characteristics and differed uniquely in music training. However, in order to attenuate the effect of possible confounding variables, we ensured that both groups contained a similar number of males and females, and were closely matched in age, education, and verbal IQ. Moreover, we statistically controlled the effects of family income, which is highly associated with the opportunity to provide children and young adults with music training. In that sense, the two groups were matched as closely as possible. Another potential confounding variable for the cognitive benefits of music training could be that musicians were advantaged by a higher general IQ than non-musicians. The two groups were very similar regarding verbal IQ, but other aspects of intelligence were not tested (e.g., reasoning). Critically, because of the quasi-experimental nature of this study, cause–effect links between music training and WM enhancement could not be drawn.

CONCLUSION

The findings of the present study support the view that formal music training is positively associated with sustained attention, visual–motor coordination, visual scanning ability, visual processing speed, spatial memory, and information manipulation skills. These skills may have been promoted by music training, in general, and specifically by sight reading, which requires planning, perceptual speed, auditory imagery, and spatial memory as musicians need to read and transform music notations to motor actions very quickly. No enhanced verbal memory or visual memory for static information was observed in musicians as compared to non-musicians. The results showed that the beneficial effects of music training are not generalised to all the aspects of the WM model, but are evidenced mostly in tasks that require similar processes to those acquired during music training.

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REFERENCES

Aleman, A., Nieuwenstein, M. R., Böcker, K. B. E., & De Haan, E. H. F. (2000). Music training and mental imagery ability. *Neuropsychologia*, *38*(12), 1664–1668.

Amunts, K., Schlaug, G., Jancke, L., Steinmetz, H., Schleicher, A., Dabringhaus, A., & Zilles, K. (1997). Motor cortex and hand motor skills: Structural compliance in the human brain. *Human Brain Mapping*, *5*(3), 206–215. doi:10.1002/(SICI)1097-0193

Baddeley, A. (1992). Working memory. *Science*, *255*(5044), 556–559. doi:10.1126/science.1736359

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*(11), 417–423. doi:10.1016/S1364-6613(00)01538-2

Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews. Neuroscience*, *4*(10), 829–839. doi:10.1038/nrn1201

Baddeley, A., & Della Sala, S. (1996). Working memory and executive control. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, *351*(1346), 1397–1404. doi:10.1098/rstb.1996.0123

Bäckman, L., & Molander, B. (1986). Effects of adult age and level of skill on the ability to cope with high-stress conditions in a precision sport. *Psychology and Aging*, *I*, 334–336. doi:10.1037//0882-7974.1.4.334

Berz, W. L. (1995). Working memory in music: A theoretical model. *Music Perception: An Interdisciplinary Journal*, *12*(3), 353–364.

Bishop, L., Bailes, F., & Dean, R. T. (2013). Musical expertise and the ability to imagine loudness. *PLoS ONE*, *8*(2), doi:10.1371/journal.pone.0056052

Brandler, S., & Rammsayer, T. H. (2003). Differences in mental abilities between musicians and nonmusicians. *Psychology of Music*, *31*(2), 123–138. doi:10.1177/0305735603031002290

Brochard, R., Dufour, A., & Després, O. (2004). Effect of musical expertise on visuospatial abilities: Evidence from reaction times and mental imagery. *Brain and Cognition*, *54*(2), 103–109. doi:10.1016/S0278-2626(03)00264-1

Brodsky, W., Henik, A., Rubinstein, B. S., & Zorman, M. (2003). Auditory imagery from musical notation in expert musicians. *Perception & Psychophysics*, *65*(4), 602–612. doi:10.3758/bf03194586

Brown, R. M., & Palmer, C. (2013). Auditory and motor imagery modulate learning in music performance. *Frontiers in Human Neuroscience*, *7*, doi:10.3389/fnhum.2013.00320

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

Chan, A. S., Ho, Y. C., & Cheung, M. C. (1998). Music training improves verbal memory. *Nature*, *396*(6707), 128. doi:10.1038/24075

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, *4*(1), 55–81. doi:10.1016/0010-0285(73)90004-2

Davis, A. S., & Pierson, E. E. (2012). The relationship between the WAIS-III digit symbol coding and executive functioning. *Applied Neuropsychology: Adult*, *19*(3), 192–197. doi:10.1080/09084282.2011.643958

Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: A relation mediated by executive functions. *Music Perception*, *29*(2), 195–201. doi:10.1525/mp.2011.29.2.195

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102*(2), 211–245. doi:10.1037//0033-295x.102.2.211

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

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *The Journal of Neuroscience*, *23*(27), 9240–9245. doi:10.1016/S1053-8119

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

Goldstein, E. B. (2008). *Cognitive psychology: Connecting mind, research, and everyday experience* (2nd ed.). Belmont, CA: Thomson Wadsworth.

Gordon, E. E. (1989). *Manual for the advanced measures of music audiation*. Chicago, IL: GIA Publications.

Grober, E., & Sliwinski, M. (1991). Development and validation of a model for estimating premorbid verbal intelligence in the elderly. *Journal of Clinical and Experimental Neuropsychology*, *13*(6), 933–949. doi:10.1080/01688639108405109

Gruhn, W., Galley, N., & Kluth, C. (2003). Do mental speed and musical abilities interact? *Annals of the New York Academy of Sciences*, *999*(1), 485–496. doi:10.1196/annals.1284.059

Hale, J. B., Hoeppner, J. B., & Fiorello, C. A. (2002). Analyzing digit span components for assessment of attention processes. *Journal of Psychoeducational Assessment*, *20*(2), 128–143. doi:10.1177/073428290202000202

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. doi:10.1177/0022429409332677

Helmbold, N., Rammsayer, T., & Altenmüller, E. (2005). Differences in primary mental abilities between musicians and nonmusicians. *Journal of Individual Differences*, *26*(2), 74–85. doi:10.1027/1614-0001.26.2.74

Hetland, L. (2000). Learning to make music enhances spatial reasoning. *Journal of Aesthetic Education*, *34*(3/4), 179–238.

Ho, Y., Cheung, M., & Chan, A. S. (2003). Music training improves verbal but not visual memory: Cross-sectional and longitudinal explorations in children. *Neuropsychology*, *17*(3), 439–450. doi:10.1037/0894-4105.17.3.439

Jakobson, L. S., Lewycky, S. T., Kilgour, A. R., & Stoesz, B. M. (2008). Memory for verbal and visual material in highly trained musicians. *Music Perception: An Interdisciplinary Journal*, *26*(1), 41–55. doi:10.1525/mp.2008.26.1.41

Joy, S., Fein, D., & Kaplan, E. (2003). Decoding digit symbol: Speed, memory, and visual scanning. *Assessment*, *10*(1), 56–65. doi:10.1177/0095399702250335

Kopiez, R., Weihs, C., Ligges, U., & Lee, J. I. (2006). Classification of high and low achievers in a music sight-reading task. *Psychology of Music*, *34*(1), 5–26. doi:10.1177/0305735606059102

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews. Neuroscience*, *11*(8), 599–605. doi:10.1038/nrn2882

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

Masoura, E. V., & Gathercole, S. E. (2005). Contrasting contributions of phonological short-term memory and long-term

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knowledge to vocabulary learning in a foreign language. *Memory (Hove, England)*, *13*(3–4), 422–429. doi:10.1080/09658210344000323

McPherson, G. E. (1995). The assessment of musical performance: Development and validation of five new measures. *Psychology of Music*, *23*(2), 142–161. doi:10.1177/0305735695232003

Milovanov, R., & Tervaniemi, M. (2011). The interplay between musical and linguistic aptitudes: A review. *Frontiers in Psychology*, *2*(321), 1–6. doi:10.3389/fpsyg.2011.00321

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. doi:10.1177/0956797611416999

Patston, L. L. M., Kirk, I. J., Rolfe, M. H. S., Corballis, M. C., & Tippett, L. J. (2007). The unusual symmetry of musicians: Musicians have equilateral inter-hemispheric transfer for visual information. *Neuropsychologia*, *45*(9), 2059–2065. doi:10.1016/j.neuropsychologia.2007.02.001

Ramsay, M. C., & Reynolds, C. R. (1995). Separate digits tests: A brief history, a literature review, and a re-examination of the factor structure of the Test of Memory and Learning (TOMAL). *Neuropsychology Review*, *5*(3), 151–171. doi:10.1007/BF02214760

Roden, I., Grube, D., Bongard, S., & Kreutz, G. (2014). Does music training enhance working memory performance? Findings from a quasi-experimental longitudinal study. *Psychology of Music*, *42*(2), 284–298. doi:10.1177/0305735612471239

Schellenberg, E. G. (2004). Music lessons enhance IQ. *Psychological Science*, *15*(8), 511–514. doi:10.1111/j.0956-7976.2004.00711.x

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

Sluming, V., Brooks, J., Howard, M., Downes, J. J., & Roberts, N. (2007). Broca's area supports enhanced visuospatial cognition in orchestral musicians. *The Journal of Neuroscience*, *27*(14), 3799–3806. doi:10.1523/JNEUROSCI.0147-07.2007

Steele, C. J., Bailey, J. A., Zatorre, R. J., & Penhune, V. B. (2013). Early musical training and white-matter plasticity in the corpus callosum: Evidence for a sensitive period. *The Journal of Neuroscience*, *33*(3), 1282–1290. doi:10.1523/JNEUROSCI.3578-12.2013

Stewart, L., Henson, R., Kampe, K., Walsh, V., Turner, R., & Frith, U. (2003). Brain changes after learning to read and play music. *Neuroimage*, *20*(1), 71–83. doi:10.1016/S1053-8119(03)00248-9

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics*. Needham Heights, MA: Allyn & Bacon.

Wechsler, D. (1997). *Wechsler memory scale (WMS-III)*. San Antonio, TX: The Psychological Corporation.

Wechsler, D. (2008). *Wechsler adult intelligence scale (WAIS-IV)*. San Antonio, TX: Pearson Assessment.

Williamson, V. J., Baddeley, A. D., & Hitch, G. J. (2010). Musicians' and nonmusicians' short-term memory for verbal and musical sequences: Comparing phonological similarity and pitch proximity. *Memory & Cognition*, *38*(2), 163–175. doi:10.3758/MC.38.2.163

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