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Abstract

Musical ability has been found to be associated with an enhancement of verbal working memory. In this study, we investigated whether this effect would generalize to visual-spatial working memory as would be expected if the effect were driven by general intelligence. We administered the WAIS-III Digit Span; the WMS-III Spatial Span; and the Musical Ear Test (MET), a forced-choice same/different listening task measuring musical ability, to non-musicians, amateur musicians, and expert musicians. Expert musicians significantly outperformed non-musicians on the Digit Span. Additionally, Digit Span Forward scores were found to be correlated with MET total scores and with scores on the rhythm subtest of the MET. No between-group differences were found on the Spatial Span.

Keywords

digit span, musical ability, musical competence, musical expertise, spatial span, verbal working memory, visual-spatial working memory, working memory

Introduction

Musical ability has been found to be associated with enhancements of both verbal long-term memory (Brandler and Rammsayer, 2003; Chan, Ho, & Cheung, 1998; Franklin et al., 2008; Jakobson, Lewycky, Kilgour, & Stoesz, 2008; but see Helmbold, Rammsayer and Altenmüller, 2005) and verbal working memory (WM; Franklin et al., 2008; Lee, Lu and Ko, 2007; Tierney, Bergeson and Pisoni, 2008; Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010a, 2010b). In this study, we aim to determine whether the enhancements of verbal WM associated with musical ability extend to the visual-spatial domain. The investigation of potential non-musical benefits for WM is of considerable importance as WM is a basic cognitive skill that, apart from temporarily storing information, ultimately supports thought processes (Baddeley, 2003).

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Although certain studies have found enhanced visual-spatial memory in musically trained children (e.g., Bilhartz, Bruhn, & Olson, 1999; Lee et al., 2007; Zafranas, 2004), the evidence for visual-spatial memory superiority in adult musicians is mixed. Jakobson et al. (2008) found that musicians outperformed non-musicians on the Rey Visual Design Learning Test (Rey, 1964). On the other hand, Chan et al. (1998) found no significant between-group differences when administering two tests of visual memory to musicians and non-musicians. Stoesz, Jakobson, Kilgour, and Lewycky (2007) administered the Spatial Span (SS) subtest of the Wechsler Memory Scale, Third Edition (WMS-III; Wechsler, 1997b) to musicians and non-musicians. No significant between-group differences were found (Brenda M. Stoesz, personal communication, 2 June 2010), although this finding was not reported in the 2007 article. Brandler and Rammsayer (2003) and Helmbold et al. (2005) found no significant differences between musicians and non-musicians on a test of spatial memory.

The current study is a replication and expansion of the study by Wallentin et al. (2010a) who administered the Musical Ear Test (MET; a forced-choice same/different listening task consisting of two subtests: melody and rhythm; Wallentin et al., 2010a) and an unspecified forward digit span test to three groups of Danish participants: 21 non-musicians (defined as people who did not have a history of playing an instrument and who had no current involvement in any musical activities), 21 amateur musicians (defined as musicians who had at least two years of experience playing a musical instrument and who had practiced their instrument for at least one weekly hour during the past year), and 18 expert musicians (defined as professional musicians and as alumni of or students at the Danish music academies). The authors found that non-musicians achieved significantly lower MET scores than amateurs who in turn scored significantly lower than experts. Regarding scores on the forward digit span test, the authors found that experts significantly outperformed non-musicians, but that the remaining between-group differences were non-significant. Additionally, within the two groups of musicians, the authors found a strong correlation between MET scores and the amount of weekly hours of instrument practice. Lastly, the authors found a correlation between forward digit span and MET total scores.

In the current study, we included the MET as we wanted to obtain an objective measure of the musical abilities of our participants. Furthermore, as we intended, unlike previous studies, to use a standardized, reliable and valid measure to replicate the consistently reported finding that musicians show enhanced verbal WM, we included the Digit Span (DS) subtest of the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III; Wechsler, 1997a). Finally, as we intended to investigate whether musicians would also outperform non-musicians on a test of visual-spatial WM (suggesting a general enhancement of WM in musicians), we included the WMS-III SS (Wechsler, 1997b). We selected the SS as it is claimed to be “the visual analogue of the Digit Span” (The Psychological Corporation, 1997, p. 216). Considering the unpublished SS results from the study conducted by Stoesz et al. (2007) and the mixed evidence from previous studies in general, however, we did not expect any significant between-group differences in visual-spatial WM capacity.

The MET is not explicitly defined as a test of musical aptitude or of musical achievement. Yet regarding the testing procedure, Wallentin et al. (2010a) consider Gordon’s (2007) Advanced Measures of Music Audiation (AMMA) the closest comparison. The MET and the AMMA differ in other respects, however. As an example, Wallentin et al. (2010a) state that the rhythm subtest of the MET reflects a greater variety of musical genres than does the AMMA.

As for the validity of the MET, Wallentin et al. (2010a) found a strong correlation between MET scores and scores on a musical imitation test used by the Danish musical academies when auditioning prospective students. This imitation test requires participants to imitate rhythms and melodies by clapping and singing, respectively.

The inclusion of the MET in the current study additionally allowed us to attempt to replicate other findings by Wallentin et al. (2010a): the finding that the MET is able to distinguish between non-musicians, amateur musicians, and expert musicians, and the finding that MET scores correlate with DS scores. Furthermore, we intended to investigate whether SS scores and MET scores would be similarly correlated.

Lastly, as Wallentin et al. (2010a) found DS scores to increase with musical ability, we expected to see a gradation of WAIS-III DS scores according to the musical ability of our participants. We thus expected musicians to obtain higher DS scores than non-musicians.

Method

Participants

Sixty young adults (26 female; mean age: 21.0 years, SD = 2.5, range: 18–29), all native Danes, participated in the experiment (see Table 1).

We recruited three groups of 20 volunteer participants by convenience sampling: non-musicians, amateur musicians, and expert musicians. The participants were mainly students from Aarhus, Denmark. The groups were defined using the same criteria as in the study by Wallentin et al. (2010a). Non-musicians were defined as people who did not currently play a musical instrument. Amateur musicians were defined as musicians who had been playing an instrument for at least two years and who practiced their instrument for at least an hour per week at the time of the current study. Expert musicians were defined as participants who were enrolled in one of the Danish music academies. The participants had all attended Danish elementary schools and so had attended mandatory general music classes.

The group of expert musicians consisted of students at the Royal Academy of Music in Aarhus, Denmark (17 participants) and the Academy of Music and Music Communication in Esbjerg, Denmark (3 participants). Nine of the experts were enrolled in the classical department at their academy; eleven were enrolled in the rhythmic department (i.e., jazz, rock, latin, etc.). This distinction between classical and rhythmic music is widely used at the musical academies in Denmark.

The majority of the amateurs (13 participants) were enrolled in a music course at Testrup Højskole, a local *folk high school*, defined by *Encyclopædia Britannica* as a type of residential school (Folk high school, n.d.). This type of school is common in Scandinavia and popular with

Table 1. Demographics and amount of practice.

	Non-musicians (n = 20; 14 female)		Amateur musicians (n = 20; 7 female)		Expert musicians (n = 20; 5 female)			
	M (SD)	Mdn (range)	M (SD)	Mdn (range)	M (SD)	Mdn (range)	χ^2 (df)	p
Age (yrs)	20.4 (1.3)	20 (18–23)	21.2 (2.9)	20.5 (18–29)	21.7 (2.9)	21 (18–29)	1.6 (2)	= .46
Education (yrs)	13.2 (1.5)	12 (12–16)	13.25 (2.1)	12.5 (10–19)	13.35 (2.9)	12 (9–21)	0.04 (2)	= .98
Weekly practice (hrs)	0.0 (0)	0.0_a (0–0)	10.5 (4.8)	10.0_b (1–22)	23.5 (9.8)	20.5_c (10–40)	49.5 (2)	< .001
Instrument experience (yrs)	0.3 (1.1)	0.0_a (0–5)	8.3 (4.6)	8.0_b (2–18)	10.5 (4.4)	10_b (4–21)	40.2 (2)	<.001

Note. Medians with differing subscripts within rows denote significantly different distributions based on Mann-Whitney follow-up tests with Bonferroni-corrected alpha levels of .0167 per test.

Table 2. Primary instruments played by participating musicians.

	Frequency	
Instrument	Amateurs	Experts
Guitar	9	5
Piano	5	4
Organ	0	2
Violin	2	2
Saxophone	1	2
Cello	1	1
Double bass	0	1
Trombone	1	1
Bass guitar	0	1
Drums	1	1

young adults. Of the remaining amateurs, two were enrolled in other courses at Testrup folk high school, two studied at Aarhus University, one studied at the Danish School of Media and Journalism in Aarhus, one attended preparatory school (the Danish *Højere Forberedelseseksamen*), and one worked as a substitute teacher. Of the amateur musicians, 6 considered themselves primarily classical musicians, while 14 considered themselves primarily rhythmic musicians. Table 2 shows the instruments played by participating musicians.

The majority of the non-musicians (16 participants) were enrolled in other, non-music, courses at Testrup folk high school. The remaining non-musicians studied at Aarhus University or at the Aarhus School of Business. All of the participating non-musicians, except one, had no history of playing an instrument. A single participating non-musician had received five years of flute lessons during elementary school, but considered himself a non-musician at the time of the current study.

Stimuli and Procedure

Participants completed a questionnaire detailing their age, gender, and years of education. Additionally, musicians specified their primary instrument, the amount of weekly hours they currently spent practicing their instrument, and the amount of years they had been playing the instrument.

We administered the WAIS-III DS and WMS-III SS tests according to their respective manuals (Wechsler, 1997a, 1997b). Participants also completed the MET.

The DS consists of two subtests. During the Forward subtest, the experimenter reads sequences of digits aloud to the participant at a rate of one digit per second. When the experimenter finishes reading, the participant is to repeat the digits in the same order. Digit sequences start at a length of two digits. The sequence length increases by one digit when two trials of the same length have been completed. Testing is discontinued when the participant is incorrect on two trials of the same length. The Forward subtest yields a raw score equal to the number of correct trials and a score equaling the length of the longest sequence remembered correctly (Longest Digit Span Forward; LSDF). The Backward subtest is identical to the Forward subtest, except that participants must repeat digits in reverse order. The Backward subtest similarly yields a raw score and a Longest Digit Span Backward score (LDSB).

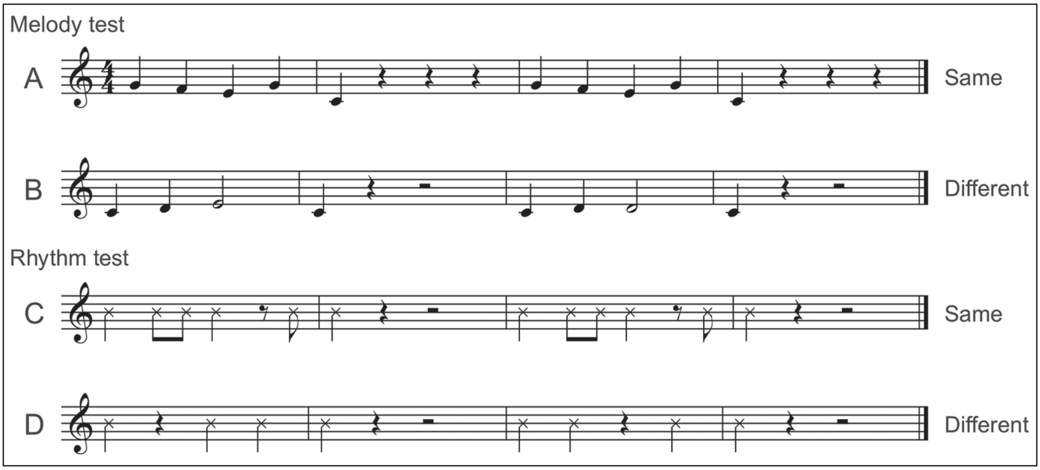

Figure 1. MET sample trials.

The WMS-III SS is administered using a plastic board with ten fixed plastic cubes that are visually identical from the participant's point of view. The experimenter points at sequences of cubes. Then, the participant is to point at the same sequence of cubes in the same order (Forward subtest), or in reverse order (Backward subtest). The sequence length increases according to the principle used on the DS. The SS also yields Forward and Backward raw scores as well as Longest Spatial Span Forward (LSSF) and Longest Spatial Span Backward (LSSB) scores.

The MET consists of a recording of musical phrases and is divided into two subtests: a melody subtest with 52 pairs of short melodic phrases played on a piano, and a rhythm subtest with 52 pairs of short rhythmic phrases played on a woodblock (see Figure 1, sample phrases). Participants listen to the recording and indicate on a response sheet whether phrase pairs are identical or different. Participants receive two subtest scores corresponding to the number of correctly answered trials. The total score is the sum of the subtest scores. The MET has a duration of approximately 18 minutes.

Results

We used the software environment R (R Development Core Team, 2010) and the graphical user interface R Commander (Fox et al., 2010) to perform the statistical analyses. Where Kolmogorov-Smirnov tests showed non-normal data, we used non-parametric tests. Otherwise, we used parametric tests. Unless otherwise noted, the alpha level for all statistical tests was .05. However, where Kruskal-Wallis tests showed significant differences between groups, the alpha levels of the Mann-Whitney follow-up tests were corrected to .0167 per test using the Bonferroni procedure.

Demographics

Kruskal-Wallis tests showed that neither age nor years of education differed significantly between groups (see Table 1). Additionally, no significant correlations (Spearman's rho) were found between test scores (all measures of the DS, the SS, and the MET) and demographic data (age and years of education).

Since a large majority of the non-musicians were female and the majority of the amateur and expert musicians were male, we performed chi-square tests in order to test gender distributions of the three groups. Gender was not equally distributed in the three groups, $\chi^2(df = 2, n = 60) = 9.1$, $p = .01$. Pairwise comparisons of groups showed that the gender distribution of the non-musicians differed significantly from that of the amateurs, $\chi^2(df = 1, n = 40) = 4.9$, $p = .03$; and from that of the experts, $\chi^2(df = 1, n = 40) = 8.1$, $p = .01$. The gender distributions of the amateurs and of the experts did not differ significantly from each other, $\chi^2(df = 1, n = 40) = 0.5$, $p = .49$.

WAIS-III Digit Span

Kruskal-Wallis tests showed significant differences between the LDSF scores of the groups (see Figure 2 and Table 3). Mann-Whitney follow-up tests showed that expert musicians differed significantly from non-musicians. The results of the remaining follow-up tests showed no other significant differences. No significant differences were found between groups for LDSB scores.

When comparing raw scores, the same pattern emerged. Kruskal-Wallis tests showed significant differences between DS Forward raw scores (see Table 3). Mann-Whitney follow-up tests showed that expert musicians differed significantly from non-musicians. The results of the

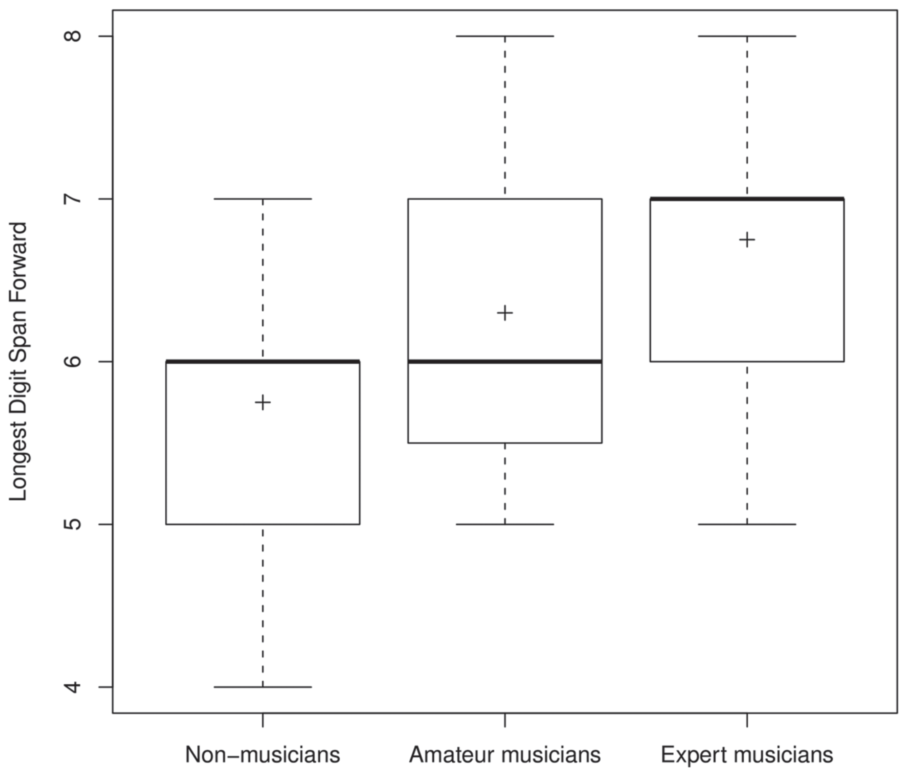

Figure 2. Box plots (see e.g., Field, Miles, & Field, 2012, pp. 144–148) of DS scores. Horizontal lines below and above the boxes represent minima and maxima, respectively; boxes represent interquartile ranges; bold lines represent medians; the plus sign represents the mean.

Table 3. WM test scores.

	Non-musicians		Amateur musicians		Expert musicians			
	M (*SD*)	*Mdn* (range)	*M* (*SD*)	*Mdn* (range)	*M* (*SD*)	*Mdn* (range)	χ^2 (*df*)	p
WAIS-III DS								
Forward, raw	8.45 (1.6)	9_a (5–11)	9.35 (1.8)	9 (7–13)	9.90 (1.3)	10_b (7–12)	8.1 (2)	= .02
Forward, LDSF	5.75 (1.0)	6_a (4–7)	6.30 (1.0)	6 (5–8)	6.75 (0.9)	7_b (5–8)	9.8 (2)	< .01
Backward, raw	6.65 (1.6)	7 (4–11)	6.70 (1.9)	7 (3–11)	6.55 (1.8)	6 (4–10)	0.3 (2)	= .85
Backward, LDSB	4.75 (0.9)	5 (3–7)	4.95 (1.1)	5 (3–7)	4.75 (1.0)	5 (3–6)	0.3 (2)	= .87
WMS-III SS								
Forward, raw	9.15 (1.8)	9.5 (6–12)	9.80 (1.8)	10 (6–12)	9.90 (1.7)	10 (6–14)	1.7 (2)	= .43
Forward, LSSF	6.10 (1.1)	6 (4–8)	6.65 (0.9)	7 (4–8)	6.55 (0.9)	6.5 (4–8)	2.8 (2)	= .25
Backward, raw	9.35 (1.5)	9.5 (6–12)	9.05 (1.2)	9 (6–11)	9.05 (1.3)	9 (6–11)	0.8 (2)	= .69
Backward, LSSB	6.15 (0.7)	6 (4–7)	6.00 (0.8)	6 (4–7)	6.05 (0.9)	6 (4–8)	0.5 (2)	= .78

Note. Medians with differing subscripts within rows denote significantly different distributions based on Mann-Whitney follow-up tests with Bonferroni-corrected alpha levels of .0167 per test.

remaining follow-up tests showed no other significant differences. Furthermore, no significant differences were found between groups for DS Backward raw scores.

WMS-III Spatial Span

SS scores were compared using Kruskal-Wallis tests. No significant differences were found between LSSF scores; or between LSSB scores. Similarly, no significant differences were found between SS Forward raw scores; or between SS Backward raw scores (see Table 3).

The Musical Ear Test

We conducted one-way analyses of variance of the MET subtest scores and of the total scores (see Table 4). We found that subtest scores and total scores differed significantly between groups. Post hoc comparisons using Tukey's Honestly Significant Difference (HSD) showed the same pattern across the subtest scores and the total scores: non-musicians differed significantly from both amateurs and experts, whereas the differences between amateur musicians' and expert musicians' scores were not statistically significant at $p < .05$ (see Figure 3).

We used Spearman's rank correlation coefficient as a measure of dependence between participants' WM test scores (all measures of DS and SS) and their MET scores. We used Holm's (1979) method to correct for multiple inference. DS raw scores were found to be significantly correlated with scores on the rhythm subtest of the MET and with MET total scores (see Table 5). No other significant correlations were found between scores on the WM tests and the MET scores.

Scores on the two MET subtests were found to be correlated ($n = 60$, $r = .55$, $p < .001$).

Amount of practice

Kruskal-Wallis tests showed that the groups differed significantly regarding hours of weekly instrument practice and regarding years of instrument experience (see Table 1). Follow-up Mann-Whitney tests showed that amateurs practiced significantly fewer hours per week than did experts, $z = -4.3$, $p < .001$. Non-musicians practiced significantly less than did amateurs, z

Table 4. MET scores.

	Non-musicians	Amateur musicians	Expert musicians		
	M (SD)	M (SD)	M (SD)	F (df)	p
Musical Ear Test					
Melody	66.83_a (7.7)	80.96_b (8.8)	86.06_b (7.3)	31.2 (2,57)	< .001
Rhythm	70.10_a (9.2)	79.81_b (7.9)	81.06_b (7.5)	10.6 (2,57)	< .001
Total	68.46_a (6.7)	80.38_b (6.3)	83.56_b (6.6)	29.6 (2,57)	< .001

Note. Means with differing subscripts within rows are significantly different at $p < .01$ based on Tukey's HSD post hoc comparisons.
All MET mean scores are percentages.

Table 5. Correlations between WM tests and the MET.

	Musical Ear Test		
	Melody	Rhythm	Total
WAIS-III Digit Span			
Forward, raw score	.32	.47‡	.44†
Forward, LDSF	.31	.36	.37
Backward, raw score	.05	.17	.12
Backward, LDSB	.13	.21	.20
WMS-III Spatial Span			
Forward, raw score	.23	.06	.16
Forward, LSSF	.23	.05	.16
Backward, raw score	–.10	.05	–.04
Backward, LSSB	–.14	.03	–.06

Note. †$p = .02$, ‡$p = .006$.

$= -5.8$, $p < .001$, and significantly less than did experts, $z = -5.8$, $p < .001$. Regarding years of instrument experience, Mann-Whitney tests showed no significant differences between amateurs and experts, $z = -1.5$, $p = .12$. Non-musicians were significantly less experienced than amateurs, $z = -5.5$, $p < .001$, and were significantly less experienced than experts, $z = -5.6$, $p < .001$. When looking at the musician groups, hours of weekly practice was found not to be significantly correlated with MET total score ($n = 40$, $r_s = .02$, $p = .91$).

Discussion

Summary of findings

Expert musicians exhibited greater verbal WM storage capacity than did non-musicians (as reflected by DS Forward scores). These results are consistent with previous studies comparing the digit spans of musicians and non-musicians (Lee et al., 2007; Wallentin et al., 2010a). Furthermore, the results complement studies reporting enhanced verbal WM in adult musicians (Franklin et al., 2008; Lee et al., 2007; Parbery-Clark, Skoe, Lam, & Kraus, 2009). No significant demographic differences were found between groups, suggesting that musicians' digit span enhancements are unlikely to have been driven by such differences.

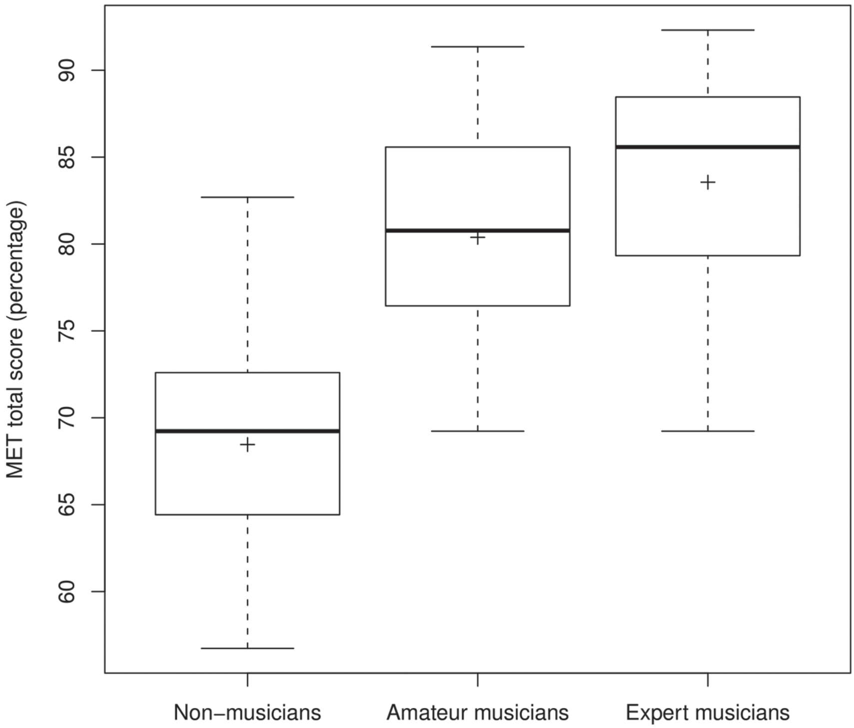

Figure 3. MET scores; box plots (see e.g., Field et al., 2012, pp. 144–148) of MET scores.

DS Backward scores did not, however, differ across groups, suggesting that the WM enhancements found in musicians are limited to a greater storage capacity and do not extend to the manipulation of verbal material in WM. The lack of significant between-group differences on the DS Backward is in line with results reported by Lee et al. (2007).

No significant differences were found for SS Forward or Backward scores. Thus, these results are consistent with other studies reporting no visual-spatial WM enhancements for musicians (Brandler & Rammsayer, 2003; Chan & Kwok, 1999; Helmbold et al., 2005).

Expert musicians significantly outperformed non-musicians on the MET. While experts did achieve higher mean MET scores than amateurs, this between-group difference was not statistically significant. This may be explained by the fact that the majority of the amateurs were enrolled in a music course at a folk high school. Thus, it is likely that a large portion of the amateurs could be considered highly skilled musicians close to the level of skill required to enter the music academies, at least regarding listening skills. The discrepancy may also be due to our definition of amateur musicians, which did not specify maximum levels of practice or experience. The amateur musicians tested by Wallentin et al. (2010a) may have been less musically skilled than the amateur group in the present study. Indeed, the present amateurs and experts did not differ significantly regarding years of instrument experience, suggesting that the present amateur group consisted of dedicated and considerably skilled musicians. In the study by Wallentin et al. (2010a), the age-matched amateurs and experts significantly differed regarding age of onset of instrument practice, likely reflecting a greater difference of instrument experience than that observed in the current study.

Interestingly, DS Forward scores were found to be correlated with MET total scores and with scores on the rhythm subtest. Wallentin et al. (2010a) reported similar findings, but also found a correlation between digit span scores and the melody subtest. Similarly, Saito (2001) found significant correlations between digit span and performance on a rhythmic imitation test. Additionally, other studies have found significant correlations between musical training and forward digit span (Anvari, Trainor, Woodside, & Levy, 2002; Schellenberg, 2006), although in children.

In contrast to Wallentin et al. (2010a), we did not find MET scores and hours of weekly practice to be significantly correlated. Further research using more accurate measures of weekly practice is needed to clarify this discrepancy. Performance on the MET subtests was found to be correlated, replicating findings reported by Wallentin et al. (2010a). Non-musicians obtained higher mean scores on the rhythm subtest than on the melody subtest, whereas amateurs and experts both obtained higher melody subtest scores than rhythm subtest scores. The same pattern emerged in the three experiments reported by Wallentin et al. (2010a). Therefore, there is a possibility that musical training might especially improve melodic discrimination abilities.

Gender differences in digit span

The gender distribution was unequal across groups, so one might argue that the differences in DS Forward scores could have been driven by gender differences. We consider this unlikely, however, as one study (Orsini et al., 1986, 1987) compared the WAIS DS of 1355 randomly selected Italian adults aged 20–99 and found no significant gender differences.

Transfer between non-musical and musical skills

Although musical training has been associated with enhanced performance on measures of spatial abilities, such as three-dimensional mental rotation (Sluming, Brooks, Howard, Downes, & Roberts, 2007), the WAIS-III Block Design, and the copying of physically impossible objects (Stoesz et al., 2007), the present results do not suggest that musical ability is associated with enhancements of visual-spatial WM.

Why might this be the case? Remembering sequences of cubes might appear similar to remembering, for instance, how to play a melody on the piano. After all, both tasks involve using one's fingers to touch or depress a set of physical objects. Unlike keys on a piano, however, the SS cubes do not provide auditory feedback when touched. Moreover, the cubes are not arranged in a systematic fashion. In contrast, piano keys are arranged systematically according to pitch. Furthermore, musicians have conceptual knowledge of scale degrees and notes, for example, which presumably facilitates chunking (i.e., the grouping of stimuli into meaningful larger units; Miller, 1956), which in turn could improve recall of musical phrases, similar to how expert chess players have been found to efficiently encode board positions (Chase & Simon, 1973). Thus, the similarities between the SS task and musical tasks performed regularly by instrumentalists might be too superficial for any transfer of skills to occur.

In comparison, the DS requires participants to attend to and mentally rehearse auditory stimuli. A musical task analogous to the DS would be the act of listening to and imitating melodies or rhythms. Musicians do this when learning new material by ear, for example. Both musical imitation and the DS task involve attending to auditory imagery and determining the temporal order of items in auditory WM. Moreover, the use of subvocalization as a rehearsal strategy is appropriate on both tasks. A reasonable hypothesis, then, would be that musical training involving temporal scanning of auditory stimuli and subvocal rehearsal might cause musicians to become better than non-musicians at performing these tasks. This, in turn, might result in an improved verbal WM storage capacity. Below, we discuss research findings consistent with this hypothesis.

Regarding the ability to determine the temporal order of items in auditory WM, musicians have been shown to outperform non-musicians on a test requiring participants to determine the temporal order of two syllables embedded in a sequence of four syllables (Jakobson, Cuddy, & Kilgour, 2003). It appears, then, that musicians are less likely to confuse the temporal order of verbal material in working memory. This would certainly be beneficial in regards to the DS test.

Another plausible explanation for musicians' superior DS performance would be that musicians employ a strategy of subvocalizing digits. Franklin et al. (2008) showed that musicians outperformed non-musicians on a word-list memory test, but when participants performed articulatory suppression during memorization, preventing subvocalization, no between-group differences were found. It should be noted, however, that Helmbold et al. (2005) – in a study that did not introduce articulatory suppression – did not find any significant differences in verbal memory scores between musicians and non-musicians. Although Franklin et al. were measuring long-term memory, musicians may plausibly be relying on subvocalization as a memorization strategy during digit span testing as well.

Yet another possible explanation would be that musicians' verbal WM superiority relies on categorization of the semantic content of the digit sequences. Such semantic categorization might facilitate recall. However, Lee et al. (2007) found that musicians also outperformed non-musicians on a non-word span test, a test identical to the DS Forward, except that it replaces digits with nonsense syllables. Thus, musicians appear not to rely on the semantic content of the material in auditory WM, as the results reported by Lee et al. show that musicians are capable of outperforming non-musicians on auditory WM tests even when prevented from using semantic clustering as a memorization strategy.

Musicians' verbal WM superiority might also rely on a superior perception of auditory stimuli. Musicians have been found to outperform non-musicians when discriminating linguistic intonation (Marques, Moreno, Luís Castro, & Besson, 2007; Schön, Magne, & Besson, 2004), emotional speech (Thompson, Schellenberg, & Husain, 2003, 2004), lexical stress (Kolinsky et al., 2009), lexical tone (Delogu, Lampis, & Belardinelli, 2010), and speech in noise (Parbery-Clark et al., 2009). One might hypothesize, then, that this enhanced ability to differentiate and perceive subtleties of sound, including speech, might improve recall. Further research is needed to verify this.

Moreover, it is reasonable to hypothesize that musicians might expand their auditory WM storage capacity through musical training, given that previous fMRI studies (Hickok, Buchsbaum, Humphries, & Muftuler, 2003; Koelsch et al., 2009) have found that similar neuronal networks are activated during the rehearsal and storage of verbal and of tonal stimuli. In line with these findings, another fMRI study (Schulze, Zysset, Mueller, Friederici, & Koelsch, 2011) comparing non-musicians and musicians found that both groups activated a similar set of neuronal networks during rehearsal of verbal and of tonal stimuli. The authors also found, however, that musicians activated two subnetworks in addition to this core network; one network during rehearsal of verbal stimuli, and another during rehearsal of tonal stimuli. Nonetheless, while musicians may have specialized subnetworks of auditory

WM, it is possible that musical training involving the use of tonal WM might improve the efficiency of the core neuronal network shared by tonal and verbal WM. As musical training is known to enhance myelination and cause increases in grey matter volume of brain structures implicated in music performance (for a review, see Munte, Altenmüller, & Jancke, 2002), it is plausible that an increased efficiency, brought about by musical training, of the core neuronal network implicated in tonal and verbal WM might result in enhancements of verbal WM.

If musical training does enhance verbal WM, one would then expect children receiving music lessons to show greater verbal WM improvements over time than children receiving other types of lessons, or no lessons. However, the evidence from longitudinal studies is mixed. Fujioka, Ross, Kakigi, Pantev, & Trainor (2006) found no significant differences at baseline in the WISC-III Digit Span (Wechsler, 1991) scores of children assigned to a year of Suzuki music lessons and of children assigned to no lessons. At post-test, however, the Suzuki group had improved their scores significantly, unlike controls. Similarly, Schellenberg (2004) found significantly improved WISC-III DS scores in children assigned to 9 months of musical training compared to control children. On the other hand, Moreno et al. (2009) assigned children to 6 months of music or painting lessons, but found no significant between-group differences in WISC-III DS scores at post-test. These results might suggest that a certain amount of musical training is necessary in order for enhancements of verbal WM to develop.

Future studies

Future studies should further investigate the extent of the verbal WM enhancements associated with musical ability, considering the present findings and those reported by Lee et al. (2007) suggesting that musical ability is associated with greater storage, but not manipulation, of material in verbal WM. While the present study adds to a growing body of evidence showing verbal WM enhancements in musicians, the direction of causality cannot be determined. Although several longitudinal studies (Fujioka et al., 2006; Moreno et al., 2009; Schellenberg, 2004) have compared digit span scores in children assigned to music lessons or to control conditions, the evidence from these studies is, as mentioned, mixed. Thus, more research is needed to determine whether musical training has a beneficial effect on verbal WM. Ideally, future longitudinal studies should follow participants for longer periods of time, as differences may require longer periods of practice in order to develop.

Conclusion

Using a standardized measure of verbal WM, the WAIS-III DS, we confirmed the association between musical ability and enhancement of verbal WM storage capacity as measured by the DS Forward subtest. We did not, however, find any significant between-group differences on the DS Backward subtest, suggesting that musicians' WM enhancements do not extend to the manipulation of items in verbal WM. We also did not find any significant between-group differences regarding visual-spatial WM as measured by the WMS-III SS. This finding suggests that musicians' WM enhancements does not extend to the visual-spatial domain. Lastly, we confirmed the ability of the MET to distinguish between musicians and non-musicians, but did not confirm its ability to distinguish between amateurs and experts.

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