The Effect of Background Music on Cognitive Performance in Musicians and Nonmusicians

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There is debate about the extent of overlap between music and language processing in the brain and whether these processes are functionally independent in expert musicians. A language comprehension task and a visuospatial search task were administered to 36 expert musicians and 36 matched nonmusicians in conditions of silence and piano music played correctly and incorrectly. Musicians performed more poorly on the language comprehension task in the presence of background music compared to silence, but there was no effect of background music on the musicians' performance on the visuospatial task. In contrast, the performance of nonmusicians was not affected by music on either task. The findings challenge the view that music and language are functionally independent in expert musicians, and instead suggest that when musicians process music they recruit a network that overlaps with the network used in language processing. Additionally, musicians outperformed nonmusicians on both tasks, reflecting either a general cognitive advantage in musicians or enhancement of more specific cognitive abilities such as processing speed or executive functioning.

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Performing music is an activity that trains complex cognitive and motor skills. Musicians typically begin to study and practice their instrument/s in childhood when the potential for neural plasticity is at its peak. It is thus not surprising that a significant literature points to anatomical and functional differences between the brains of expert musicians and nonmusicians (Gaab & Schlaug, 2003; Jäncke, 2009; Münte, Altenmüller, & Jäncke, 2002; Schlaug, Jäncke, Huang, & Steinmetz, 1995; Stewart, 2008). Relatively few studies, however, have attempted to relate these neural differences to behavioral correlates.

Most studies that have investigated associations between music training and cognitive abilities have concentrated on children, typically comparing participants who receive music lessons to those who do not. Music training is associated with enhanced cognitive abilities that extend beyond cognitive processes related directly to music, such as mathematical abilities (Cheek & Smith, 1999; but see also Forgeard, Winner, Norton, & Schlaug, 2008; Haimson, Swain, & Winner, 2011), visuospatial abilities (Bilhartz, Bruhn, & Olson, 2000; Graziano, Peterson, & Shaw, 1999; Rauscher, Shaw, & Levine, 1997; Rauscher & Zupan, 2000), and literacy (Forgeard et al., 2008; Gromko, 2005; Moreno et al., 2009; Schlaug, Norton, Overy, & Winner, 2005; Standley & Hughes, 1997). Unfortunately, in most studies that use this quasi-experimental approach, alternative explanations cannot be ruled out. For example, superior performance by those receiving lessons may be due to the positive effects of extra instruction or to the effects of extra attention by an adult. Alternatively, music lessons may induce generally heightened mood and motivation, which, in turn, affect cognition and cognitive development. Children with above-average cognitive abilities may also be more likely than other children to take music lessons (Schellenberg, 2006, 2011).

Schellenberg (2004) addressed these alternative explanations by including a control group that received drama lessons when investigating the impact of music training on general intellectual ability. Children (144 6-year olds) were randomly assigned to the different groups, which allowed for inferences of causation. The drama group received the same potential beneficial side effects of music lessons, such as attentional input from an adult and enhanced motivation, but without the music. The subsequent relative increase in general full-scale IQ (measured by the WISC-III) of both music groups when combined (keyboard and voice lessons) compared to the drama group could not, therefore, be ascribed to more

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positive experiences with adults. The results of this study allowed for the inference that just 36 weeks of music training (with minimal time spent practicing at home) causes a small but reliable increase in full-scale IQ in children.

Norton et al. (2005) conducted a longitudinal study examining associations between music training and cognitive and brain development. They asked whether there are pre-existing cognitive and/or anatomical differences in children who practice music and those who do not. They also sought to document the cognitive and neural development of all the children (who were not randomly assigned), regardless of whether they dropped out of lessons or went on to become musically proficient. At baseline, there were no cognitive (visual-spatial, verbal, music perception), motoric, or structural brain differences between those intending to start music lessons and those without such intentions. In other words, at the outset of lessons the two groups could not be differentiated. In a follow-up study with a subsample of the same children, structural brain changes were evident in musically relevant areas (motoric and auditory) among children with 15 months of music training (Hyde et al., 2009). These children, however, did not show greater visuospatial or verbal gains when compared to the nonmusic group. As the authors acknowledged, 15 months of training may not be long enough to develop detectable differences on the types of cognitive tasks they administered, although Schellenberg (2004) demonstrated cognitive effects after only 36 weeks. The failure of Hyde et al. to replicate Schellenberg's result may also have been due to a small sample and low power rather than to a genuine lack of training effects.

Researchers have compared the performance of musically trained and untrained adults on nonmusical tasks, with findings frequently revealing positive associations between musical expertise and cognitive abilities (e.g., Brochard, Dufour, & Despres, 2004; Chan, Ho, & Cheung, 1998; Nering, 2002; Overy, 1998). Like the studies with children, however, these studies with adults are often based on self-selected groups that may differ in more ways than music experience. Nevertheless, when Brandler and Rammsayer (2003) used similarly high-functioning participants in their control group (i.e., all participants were graduate students), nonmusicians outperformed the musicians on all four of Cattell's Culture Free Intelligence (short version) subtests, while musicians outperformed nonmusicians on a single test of verbal memory. In a later study, Helmbold, Rammsayer, and Altenmüller (2005) doubled their participant pool and all the previously significant differences between groups became nonsignificant. The musicians, however, now outperformed the nonmusicians on tests of flexibility of closure and perceptual speed. In both studies, multiple tests inflated the probability of finding some group differences by chance.

There is substantial evidence that nonmusicians' brains are different from musicians' brains, which have, for example, atypical lateralization of function (Jäncke, 2009; Stewart, 2008). We have previously demonstrated differences in the neural organization of nonmusical functions in expert adult musicians. In an EEG study, expert musicians displayed transfer of visual information as fast from right-to-left hemispheres as from left-to-right, whereas nonmusicians showed the standard faster transfer of visual information from right-to-left (Patston, Kirk, Rolfe, Corballis, & Tippett, 2007). Expert musicians also were more likely than nonmusicians to attend equally to the left and right sides of space when processing visuospatial stimuli (Patston, Corballis, Hogg, & Tippett, 2006; Patston, Hogg, & Tippett, 2007). These findings suggest that in addition to generally above-average performance on many cognitive tasks, extensive music training from a young age may alter the underlying neural organization of nonmusical cognitive abilities.

Because the right hemisphere is typically dominant for visuospatial processing (Fink et al., 2000; Geschwind & Galaburda, 1985; Heilman, Jeong, & Finney, 2004; Mattingley, Bradshaw, Nettleton, & Bradshaw, 1994), our results imply a leftward shift in lateralization of these functions in expert musicians. This tendency has been evident in other imaging studies (Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005; Schneider et al., 2002; Sluming, Brooks, & Howard, 2007). For instance, Schneider et al. (2002) reported gray matter increases in Heschl's gyrus (an auditory processing region) in professional musicians. Specifically, gray matter volume was 15% larger in the right hemisphere of musicians compared to nonmusicians, but 19% larger in the left hemisphere. Gaser and Schlaug (2003) also reported positive correlations between music expertise and an increase in volume of several areas of gray matter, including the left cerebellum, left Heschl's gyrus, and left frontal gyrus.

There is also evidence that music processing itself is more left lateralized in musicians than in nonmusicians. Music processing is coarsely right hemisphere dominant in neurologically typical individuals (Kimura, 1964; Milner, 1962), although this view is rather oversimplified (Peretz & Zatorre, 2005). Yet whereas rhythm is processed primarily by the left hemisphere (Di Pietro, Laganaro, Leemann, & Schnider, 2004: Vignolo, 2003), most other aspects of music, such as pitch, contour, meter, melody, perception, imagery, and emotion, are processed primarily by the right hemisphere in nonmusicians (Blood, Zatorre, Bermudez, & Evans, 1999; Brown, Martinez, & Parsons, 2004; Liégeois-Chauvel, Peretz, Babaï, Laguitton, & Chauvel, 1998; Penhune, Zatorre, & Feindel, 1999; Tramo, Shah, & Braida, 2002; Zatorre & Halpern, 1993; Zatorre & Samson, 1991). In musicians, however, the dominance of the right hemisphere for music processing seems to be less pronounced.

In an early study, Bever and Chiarello (1974) reported that musicians have a right ear advantage when processing musical stimuli, pointing to left hemisphere dominance. The authors speculated that this was due to musicians' more analytical approach to music listening. Although these results have not been replicated, other studies using EEG and fMRI have provided evidence consistent with the findings of Bever and Chiarello (Bhattacharya & Petsche, 2001; Schmithorst & Holland, 2003). For example, Fabbro, Brusaferro and Bava (1990) reported that expert musicians showed left hemisphere superiority on a manual interference tapping paradigm that involved tapping while singing and whistling. Similarly, Baumann et al. (2007) reported greater left hemisphere activation in pianists than nonmusicians when listening to music. Furthermore, in an fMRI study that involved listening to music, Bangert et al. (2006) found that compared to nonmusicians, musicians had activation in a distinct network in the left hemisphere that extended from the left primary motor cortex to frontal areas and the superior portion of Broca's area. The authors speculated that: "Maybe the simplified notion popular in the 70s and 80s that music processing is generally lateralized to the right in nonmusicians, but 'switches' to the left in the course of becoming a professional musician...still has some truth to it" (p. 923).

In sum, although it is clear from the extensive literature on music processing that the two hemispheres have complementary roles in the perception of music, the extent to which each hemisphere is involved seems to differ in musicians compared to nonmusicians. Some studies investigating musical expertise have also reported leftward shifts in musicians in language lateralization. For example, Broca's area has been found to be larger in musicians (Sluming et al., 2002) and used in mental rotation tasks by musicians but not by nonmusicians (Sluming, Brooks, Howard, Downes, & Roberts, 2007).

There is great interest in the commonalities and differences between music and language due to the central role both play in our everyday lives (Patel, 2008), and many researchers have investigated the neural networks responsible for both domains. Currently there is debate concerning the extent of the overlap between music and language processing in the brain. Peretz and colleagues have worked extensively with individuals with acquired and congenital amusia who show dissociation between music and language abilities, which is consistent with modularity, or functional independence, of language and music (Peretz, 2001, 2009; Peretz & Coltheart, 2003). Nevertheless, other findings suggest that the networks underlying the processing of music and language may not be independent, either in musicians (Patel, 2003; Patel, Gibson, Ratner, Besson, & Holcomb, 1998; Sluming et al., 2002) or nonmusicians (Koelsch et al., 2002; Maess, Koelsch, Gunter, & Friederici, 2001). One way to determine whether the processing of music and language overlap in musicians, and thus perhaps share common underlying processing networks, would be to test for cognitive interference when processing a language task in the presence of background music, and to investigate whether such interference is greater in musicians than in nonmusicians.

Kämpfe, Sedlmeier and Renkewitz (2010) conducted a meta-analysis of the literature investigating the effects of background music in the general population. They reported small positive effects for motor behaviors, such as increased running pace when listening to fast music (Edworthy & Waring, 2006), and for emotional reactions, such as reduced nervousness when listening to music at work (Oldham, Cummings, Mischel, Schnidtke, & Zhou, 1995). In contrast, there were small negative impacts of background music on memory performance (e.g., de Groot, 2006; Nittono, 1997) and reading performance (e.g., Etaugh & Ptasnik, 1982). A study by Freeburne and Fleischer (1952), however, (not included in the Kämpfe et al. meta-analysis) found that participants read faster in the presence of music compared to silence. Although research examining the effect of background music has been conducted for some decades, to our knowledge no studies have contrasted the cognitive performance of musicians and nonmusicians in the presence of music.

In the present study, musicians and nonmusicians were compared on a language task (sentence comprehension) and a visual task (visuospatial search) under three conditions: music played correctly, music played incorrectly, and silence. Our goal was to test whether processing of music and language is functionally independent in musicians but not in nonmusicians. Because of the evidence that in musicians, music and language processing share cognitive and neural resources, we predicted that the performance of the musicians would be impaired on the language (but not the visuospatial) task in both music conditions, with the greatest impairment in the incorrect music condition. We expected performance on the visuospatial task for both musicians and nonmusicians to be unaffected by background music because visual and music processing involve separate networks.

The music-incorrect condition was included to examine whether music with “grammatical” errors played in the background would further exacerbate interference in musicians. Although it has been found that nonmusicians are as proficient as musicians at detecting musical syntactic violations such as Neapolitan 6th chords (i.e., a C# major chord in the key of C major; Koelsch et al., 2005), musicians show more pronounced ERP responses compared to nonmusicians when hearing these kinds of errors (Koelsch et al., 2002), and these responses have been localized in areas of the frontal cortex, especially in the left hemisphere in musicians (Koelsch et al., 2005). Neapolitan 6th chords are quite obvious (and even humorous) when detecting these irregularities is the main task. We aimed to investigate whether more subtle syntactical errors that were irrelevant to the main task would be perceived by participants, and whether such errors might selectively hinder the performance of musicians.

Method

Participants

The musician group comprised 36 participants (14 males) who had a minimum of 10 years of music training (M = 16.33, SD = 3.57, range: 10-27). All had started music lessons before age 13 (M = 6.17, SD = 2.04, range: 3-12), and all had achieved at least Grade 5 from the British Royal Schools of Music in theory, voice, or an instrument. (Grade 5 is an above average level of attainment in music exams that range from Grades 1 to 8.) Moreover, they could all read music and each participant had performed music at university or at a national level. Five musicians had absolute pitch. Of the 36 musicians, 35 played more than one instrument (one participant played only the piano) and 24 played three or more (M = 3.17, SD = 1.28, range: 1-7). The most commonly played instrument was the voice (n = 33), followed by the piano (n = 31), and then the violin (n = 13); four members played either the flute or oboe. Three musicians played the clarinet, viola, organ, or recorder, two played the cello, French horn, trumpet, or percussion, and one played the guitar, harpsichord, ukulele, trombone, baritone, bagpipes, cornet, or saxophone.

The nonmusician group consisted of 36 participants (13 males), each with fewer than 4 years of music training (24 had no training at all; M = 0.86, SD = 1.27, range: 0–3). None of the nonmusicians could either play or read music. General exclusion criteria included previous serious brain injury or childhood epilepsy, color blindness, English as a second language, and formal music training of more than 3 years but fewer than 10 years. All participants had normal hearing.

The musician and nonmusician groups were matched in terms of age, gender balance, and handedness as assessed by the Edinburgh laterality quotient (Oldfield, 1971). There were also no significant differences between the two groups on measures of general cognitive ability, as assessed by a measure of verbal IQ (the National Adult Reading Test, NART; Nelson & Willison, 1991), and a measure of fluid intelligence (the Matrix Reasoning Subtest of the Wechsler Adult Intelligence Scale—Third Edition; Wechsler, 1997; see Table 1). Matrix Reasoning requires reasoning, problem-solving skills, and mental-manipulation ability (Tulsky, Sakolfske, & Zhu, 2003), and is comparable to the Raven’s Standard Progressive Matrices (Raven, Raven, & Court, 1998).

Materials

Language comprehension task. A language comprehension task, created for this study, consisted of 144 seven-word sentences that were each converted into singular and plural forms as well as grammatically correct and incorrect versions, resulting in 576 items. Participants were asked to read each sentence silently and mark with a cross those that were grammatically incorrect, completing as many as possible in a period of 8 min. Different sets of sentences were used in the three conditions.

TABLE 1. Demographic Characteristics of Participants in the Musician and Nonmusician Groups.

	Musicians (N = 36)	Nonmusicians (N = 36)	Statistical values
Age	23.47 (4.91)	24.14 (7.10)	$t(70) = .46, p = .64$
Gender	14 males 22 females	13 males 23 females	$\chi(1) = .06, p = .81$
Laterality Quotient	73.72 (53.09)	71.15 (56.87)	$t(70) = .20, p = .84$
NART (2nd ed.)	110.89 (6.94)	108.28 (6.15)	$t(70) = 1.69, p = .10$
Matrix Reasoning (WAIS-III)	15.83 (1.61)	15.28 (1.98)	$t(70) = 1.31, p = .20$

Visuospatial search task. A visuospatial search task, also created for this study, comprised 360 novel designs made up of 12 geometric shapes and six, seven, or eight colored dots (red, blue, green, and yellow) arranged evenly within an 8 cm x 8 cm box (see Figure 1, color plate section). Participants were required to locate a difference between two nearly identical visual designs placed side by side and to indicate the quadrant in which this difference appeared. They were told that in the right-hand design one colored dot could have moved or changed color in comparison to the left-hand design in one of the four quadrants, which were distinguished by dashed lines. They were also given a template to refer to with the numbers 1, 2, 3, and 4 typed into the corresponding quadrants. Participants completed as many items as possible in a period of 8 min. Different sets of designs were used in the three conditions.

Experimental Conditions

All participants completed the two tasks in each of three experimental conditions: while listening to the music played correctly, the music played with errors, and in silence. Four piano pieces were used in the study: 1) Phantasie in C minor by Mozart, 2) 'O Lieb' in A♭. major by Lizst, 3) Sonata Opus 53 second movement in C major by Beethoven, and 4) Sonata Opus 54 in F major by Beethoven. The music-incorrect condition consisted of the same piano pieces as in the music-correct condition but each piece was contaminated with harmonically incorrect notes, or "mistakes," placed at approximately regular intervals throughout the piece. It was hypothesized that incorrectly played music would further exacerbate any effect seen in the musician group during task completion. Before participating in the study, participants were asked to listen to a CD of the four piano pieces played correctly five times. This manipulation ensured that all participants were equally exposed to the music prior to testing, at least from recent listening.

Procedure

Participants were tested individually in a quiet room. Testing took between 90 and 120 min to complete and breaks were given as required. Audio screening tasks and music conditions were played from a portable Discman or computer via computer speakers at a distance of one to two meters, and were set to a comfortable listening level (approximately 55 dB). The participants completed five screening tasks and then the experimental tasks. The screening tasks were: 1) the NART (Nelson & Willison, 1991), 2) the Matrix Reasoning Subtest (Wechsler, 1997), 3) Ishihara's test for color blindness (Ishihara, 1992), 4) the Edinburgh Handedness Inventory (Oldfield, 1971), and 5) a questionnaire containing items concerning demographic variables and music background and achievement. Musician participants who claimed to have absolute pitch also completed a test adapted from Baharloo, Johnston, Service, Gitschier, and Freimer (1998) to verify their status. All met the criterion for absolute pitch.

All participants completed the two tasks (language comprehension and visuospatial search) in each of the three conditions (silence, music-correct, and music-incorrect). Counterbalancing of conditions was arranged by a Latin square procedure and tasks within blocks of conditions were alternated between the language and visual tasks. After every task accompanied by music, participants were asked "Did you notice anything about the music?" and brief responses were recorded qualitatively. These responses were then coded as positive or negative instances of mistake perception.

Results

The dependent variables represented the number of correct items completed on the language comprehension and visuospatial search tasks. Separate mixed-design ANOVAs were conducted for each task with condition (silence, music-correct, and music-incorrect) as the repeated measure and group (musicians and nonmusicians) as the between-subjects factor. Musicians with absolute pitch performed no differently from other musicians and were included in the musician group for all analyses.

For the language comprehension task, a main effect of group, $F(1, 70) = 7.33$, $p = .01$, $\eta_p^2 = .10$, indicated that musicians ($M = 169.94$, $SD = 62.78$) completed more items correctly than did nonmusicians ($M = 138.17$, $SD = 43.86$). There was also a main effect of condition, $F(2, 140) = 12.71$, $p < .001$, $\eta_p^2 = .15$, with significantly reduced performance in the music-incorrect condition ($M = 143.19$; $SD = 51.17$) compared to both the music-correct condition ($M = 155.00$; $SD = 5.89$), $p = .007$, and the silence condition ($M = 163.96$; $SD = 62.17$), $p < .001$. The difference between the silence and music-correct conditions was only marginal, $p = .08$. Of particular interest was the significant interaction between condition and group, $F(2, 140) = 4.43$, $p = .02$, $\eta_p^2 = .06$. Follow-up pairwise comparisons revealed that the musicians scored higher than the nonmusicians in the conditions of silence, $p = .003$, and music-correct, $p = .008$, but not in the music-incorrect condition, $p > .1$. Alternative analyses revealed that the musicians completed significantly more items in the silence than in the music-correct condition (p = .04), and in the music-correct condition than in the music-incorrect condition (p = .002). As predicted, performance of the nonmusicians was unaffected by condition (see Figure 2).

The number of errors made by participants on the language comprehension task was low (M = 6.75, SD = 5.88). Because the number of errors was not normally distributed (several participants made no errors at all), Mann-Whitney U tests were used to test whether there were group differences in each of the three conditions (music-correct, music-incorrect, silence). Musicians made fewer errors than nonmusicians in all three conditions, ps < .05.

On the visuospatial search task, musicians (M = 83.41, SD = 18.08) completed significantly more items correctly than did the nonmusicians (M = 73.54, SD = 13.63), $F(2, 140) = 10.16$, p = .002, η_p^2=.13 (see Figure 3), but there was no group by condition interaction and no main effect of condition, Fs < 1. Because many participants did not make any errors at all, Mann-Whitney U tests were again used to test whether there was a group difference in errors in any of the three conditions. No differences were found, ps > .20. In short, although the musicians completed more items overall than nonmusicians, neither group was affected by the presence of music, whether it was played correctly or incorrectly.

On both tasks participants were asked whether they had noticed anything about the music in the two music conditions. Out of the 36 nonmusicians, 34 did not report any mistakes in the music-incorrect condition during either of the tasks, two reported there might have been mistakes in the music-incorrect condition, and one reported there might have been mistakes in the music-correct condition. Thus, the nonmusicians were not overtly aware of the mistakes in the music-incorrect condition. In striking contrast, 27 of the 36 musician participants reported having heard mistakes during one or both of the tasks in the music-incorrect condition. The number of musicians (n = 27) correctly identifying mistakes in either of the tasks in the music-incorrect condition was significantly greater than the number of nonmusicians (n = 2) identifying mistakes, $\chi^2_{(1)}$ = 36.09, p < .001. Six musicians thought that they had heard mistakes in the music-correct condition. Four of these were when the music-correct condition was presented after the music-incorrect condition, however, and thus these participants may have falsely identified mistakes due to heightened expectation.

Discussion

Musicians and nonmusicians performed a language comprehension task and a visuospatial search task under three conditions: music-correct, music-incorrect, and silence. The ability of the musicians to process and evaluate the grammaticality of sentences was significantly reduced when music was played in the background, particularly when the music contained mistakes. By contrast, there was no effect of music played either correctly or incorrectly on the musicians' performance on the visuospatial task. Moreover, the performance of nonmusicians was not affected on either the language or visuospatial search task by the presence of music played either correctly or incorrectly.

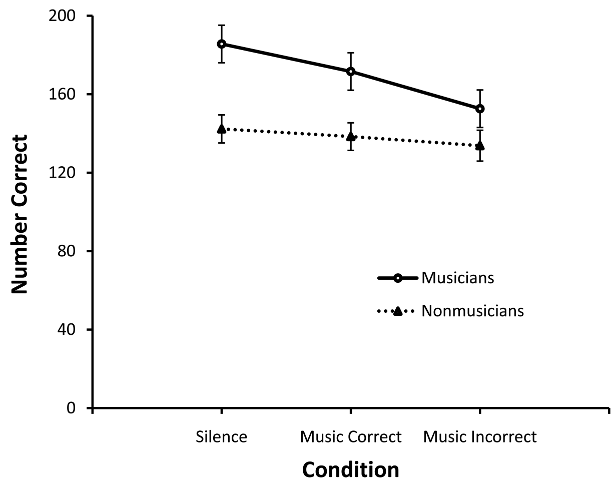

FIGURE 2. Mean number of correct items completed on the language comprehension task in three conditions for musicians and nonmusicians. Error bars represent standard errors.

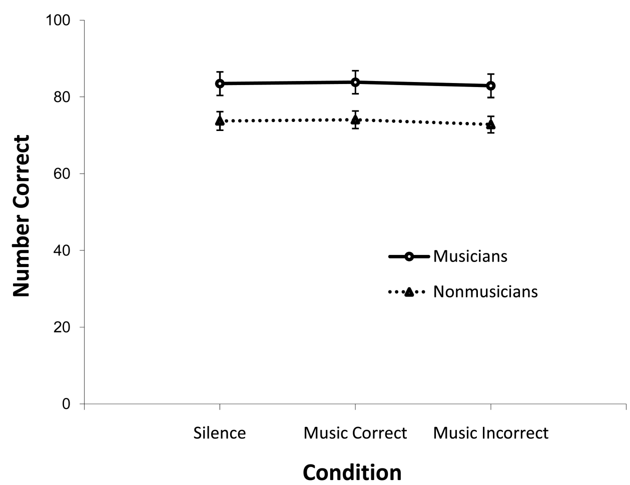

FIGURE 3. Mean number of correct items completed on the visuospatial search task in three conditions for musicians and nonmusicians. Error bars represent standard errors.

These findings challenge the view that music and language are functionally independent in expert musicians, and instead suggest that when musicians process music they recruit a network that overlaps with the network used during language processing. As a result, the presence of music interfered with the efficiency of language processing but not with visuospatial processing. Our findings suggest that for expert musicians with years of music training, the processing of music and the processing of language call upon shared cognitive and/or neural resources, and thus background music interferes with musicians' ability to process language simultaneously. The finding that musicians completed even fewer items when the background music contained harmonically inappropriate notes suggests that the interference is exacerbated by the additional processing required to parse grammatically incorrect music.

The design of our study rules out the possibility that the effect of background music on the language task for the musicians was due to increased general attentional demands when music is present (cf. Kämpfe et al., 2010). Otherwise, one might argue that the poorer performance of the musicians on the language task in the music conditions could be due to the task being more attention-demanding, possibly akin to a dual-task paradigm with increased demands on attentional resources. On this view, because the nonmusicians did not process the background music, they completed a single task—undistracted—in all three conditions. This account fails to explain, however, why musicians did not show the same decrement in performance in the visuospatial task when music was played. Indeed the absence of an effect of the music manipulation in this instance provides strong evidence that these results are not simply reflecting a dual-task phenomenon, or, more generally, a consequence of broad attentional influences.

Another possibility is that performance in the language task was affected by the music conditions because it was more difficult than the visuospatial search task. This account does not seem likely, however, because both groups completed considerably more items on the language than the visual task. Moreover, error rates on both tasks were very low for both groups.

Despite matching the musician and nonmusician groups on verbal and visual intelligence, the musician group performed at a higher level than the nonmusician group on both the language comprehension task and the visuospatial search task. This finding is consistent with much of the literature on children and music training (Schellenberg, 2004, 2005, 2006) and with some previous findings in adult populations (Brochard et al., 2004; Chan et al., 1998; Jakobson, Lewycky, Kilgour, & Stoesz, 2008; Patston et al., 2006, 2007; Schellenberg, 2006; Sluming et al., 2002). While the NART and Matrix Reasoning tests are very good predictors of verbal and fluid intelligence, respectively, it should be noted that our participants were not equated on full-scale IQ, so there remains the possibility that the musicians in this sample were more cognitively capable than those in the nonmusician group. Recent research carried out specifically to compare fluid intelligence between musicians and nonmusicians has, on the whole, reported null findings (Brandler & Rammsayer, 2003; Helmbold et al., 2005; Schellenberg & Moreno, 2010). In future studies, it might be preferable to administer the entire WAIS-III (or WAIS-IV).

Recently, Schellenberg and Moreno (2010) tested adult musicians and nonmusicians on Raven's Advanced Progressive Matrices (Raven et al., 1998) and found no difference between groups. We similarly found no difference between groups on the Matrix Reasoning subtest of the WAIS-III (Wescher 1997), which is a very similar task involving visual abstract reasoning, problem-solving skills, and mental-manipulation ability. Perhaps the advantage in performance seen in the musicians on our language and visuospatial tasks lies in enhanced motivation among musicians (cf. McAuley, Henry, & Tuft, 2011).

Processing speed has been associated with the integrity of white matter tracts (e.g., Roosendaal et al., 2009; Wilde et al., 2006), and white matter changes have been seen in studies of musicians using morphometric (Schlaug et al., 1995) and diffusion tensor imaging (Bengtsson et al., 2005; Schmithorst & Wilke, 2002). Factors such as the simultaneous bimanual requirement to play most instruments and the need to transfer visual inputs from music scores to bilateral motor outputs may stimulate myelination during music training in childhood and adolescence when plasticity is still high. This may lead to improvements in music performance and cognitive performance more generally.

Another possible explanation of the musicians' superior performance is that musicians have better executive function abilities than nonmusicians (Hannon & Trainor, 2007; Schellenberg & Peretz, 2008). Bialystok and DePape (2009) tested bilinguals, musicians, and control participants on the Simon task and found faster reaction times for bilinguals and musicians in conditions where executive control (ignoring irrelevant information) was required. Bugos, Perlstein, McCrae, Brophy, and Bedenbaugh (2007) provided older adults with 6 months of piano lessons and reported performance increases in the Trail Making Tests (Reitan & Wolfson, 1985) and the Digit-Symbol Coding subtest of the WAIS-III (Wechsler, 1997) compared to a control group. In one study of musically trained and untrained children

(Schellenberg, 2011), however, there was no difference between groups on measures of executive function despite a large between-group difference in IQ. In another study of musically trained and untrained children of the same age (Degé, Kubicek, & Schwarzer, 2011), between-group differences in executive function were evident and these differences mediated between-group differences in IQ. In short, there is emerging (but inconsistent) evidence indicating that executive function abilities may be enhanced as a result of music lessons and could, therefore, contribute positively to general cognitive functioning in musicians.

In summary, the performance of musicians was negatively affected by the presence of background music compared to silence when performing a language comprehension task involving grammaticality judgements. Their performance was not, however, affected when solving a visuospatial search task. In contrast, the performance of nonmusicians was not affected by background music on either task. These results suggest that musicians have difficulty simultaneously processing music (particularly incorrect music) and grammar, and we argue that this is due to competition in musicians between the systems that process language and music. The results presented here support the hypothesis that musicians process language and music using the same, or at least overlapping, networks, and are consistent with the view that music and language are not functionally independent, at least among musicians.

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