sempre:
Society for Education, Music and Psychology Research

Article

Psychology of Music
1–17

DOI: 10.1177/0305735618757901
journals.sagepub.com/home/pom
SAGE

Is there a specific Vivaldi effect on verbal memory functions? Evidence from listening to music in younger and older adults

Vaitsa Giannouli, Vasil Kolev and Juliana Yordanova

Abstract

Brief exposure to music has been reported to lead to transient improvement of cognitive functions in no-music domains. Regarding the possible roles of working memory, processing of acoustic regularities, arousal and emotions in mediating the effects of music on subsequent cognition, the present study explored if brief listening to music might produce a subsequent transient change of verbal functions. A large sample (n = 448) of younger (mean 28 years) and older (mean 72 years) individuals were studied to represent different background abilities. Verbal working memory (WM) and phonologically-cued semantic retrieval were assessed using the forward digit span test (F-DST) and word fluency test (WFT). To account for arousing, emotional and previous expertise effects, F-DST and WFT scores were measured only in non-musicians after listening to novel (unknown) excerpts of three different composers (Mozart, Vivaldi and Glass) and after silence, with individual preference for each condition subjectively rated. It was found that brief exposure to music had no beneficial effect on verbal WM, with even a transient impairment emerging after Vivaldi. In contrast, Vivaldi's excerpt induced a marked enhancement of word fluency, but only in young adults, whereas listening to Mozart's composition was followed by decreased WFT scores in the two age groups. These results show that depending on composer- or excerpt-specific music features, listening to music can selectively facilitate or inhibit ongoing verbal functions. It is suggested that these effects are mediated by pro-active priming or interference of residual activations induced by music in working memory loops.

Keywords

forward digit span test, Mozart effect, music preferences, Vivaldi effect, word fluency test

Institute of Neurobiology, Bulgarian Academy of Sciences, Sofia, Bulgaria

Corresponding author:
Vaitsa Giannouli, Institute of Neurobiology, Bulgarian Academy of Sciences, Acad. G. Bonchev str., bl. 23, Sofia, Bulgaria.
Email: giannouliv@hotmail.com

The effect of brief exposure to music on cognitive performance has been broadly recognized by the so-called Mozart effect, first described by Rauscher, Shaw, and Ky (1993). The Mozart effect refers to "slight and transient improvement in spational [*sic*] reasoning skills detected in normal subjects as a result of exposure to the music of Mozart, specifically his sonata for two pianos (K448)" (Pryse-Phillips, 2003). Subsequently, a variety of similar studies were performed, but some raised early doubts on the existence of the Mozart effect and/or on the replication methodologies based on different measures, procedures and tasks (Steele, Brown, & Stoecker, 1999). Although the specific Mozart effect still remains debatable (Verrusio, Moscucci, Cacciafesta, & Gueli, 2015), it has motivated extensive research on whether and how brief musical experience may affect (or possibly enhance) subsequent cognitive performance.

Whereas early investigations have focused primarily on Mozart's music and on visuospatial capacity (Verrusio et al., 2015), recent research demonstrates that brief exposure to music may prime not only visual spatio-temporal processing (Jaušovec & Habe, 2004, 2005; Rauscher et al., 1993), but also phonological working memory (Mammarella, Fairfield, & Cornoldi, 2007) and encoding and retrieval of verbal information (Ferreri, Bigand, Bard, & Bugaiska, 2015; Ferreri et al., 2014). While these previous observations point to the role of working memory in mediating the transient associations between music and cognition, the specific contributions of working memory mechanisms are not explicitly known. Moreover, according to the arousal-and-mood hypothesis (Thompson, Schellenberg, & Husain, 2001), listening to music affects cognitive performance by shifting arousal and emotional activations, rather than by modulating specific processing circuits. With regard to these considerations, the present study was undertaken to further elucidate the neurocognitive sources of the transient associations between music and subsequent cognitive performance, with a specific focus on working memory, arousal and emotional activations.

From a neurocognitive perspective, working memory subserves the temporary maintenance of relevant information for processing guided by internal and external attention (Coull, 1998). According to the model of Baddeley (1986), working memory is a three-component system, comprising a limited capacity attentional controller (*central executive*), aided by two subsystems, one concerned with acoustic and verbal information (*phonological loop*), and the other performing similar functions for visual and spatial information (*visuospatial sketchpad*). In the Mozart effect research tradition, the visuospatial sketchpad (visuospatial capacity, visual spatio-temporal processing and spatial rotation) was mainly targeted (Jaušovec & Habe, 2004, 2005; Rauscher et al., 1993). However, meta-analyses fail to support a specific, performance-enhancing Mozart effect on visuospatial tasks (Chabris, 1999; Pietschnig, Voracek, & Formann, 2010), while no reliable data exist about the Mozart effect on verbal tasks (Verrusio et al., 2015). Instead, brief exposure to Vivaldi's music has been reported to induce a significant increase in the capacity of phonological working memory (Mammarella et al., 2007), pointing to a role of the phonological loop. The association with phonological processing is also supported by observations according to which long-lasting musical training in musicians improves verbal working memory, verbal fluency and linguistic performance (Carpentier, Moreno, & McIntosh, 2016; Moreno & Bidelman, 2014; Zuk, Benjamin, Kenyon, & Gaab, 2014), and also specifically modulates speech representations by neuroplastic changes in overlapping auditory networks (Bidelman, Weiss, Moreno, & Alain, 2014; Moreno et al., 2009; Patel, 2011, 2014). Notably, the effects of music on phonological processing have been reported to depend on the skills and knowledge of how to select and produce the sounds during performance (Clayton et al., 2016; Schulze & Koelsch, 2012; Strait, Hornickel, & Kraus, 2011), pointing to the critical role of the central executive control. Also, several executive functions have been found to be superior in musicians relative to non-musicians (Zuk et al., 2014). Hence, according to previous research, exposure to music appears to recruit domain-general (central executive) and domain-specific (phonological) circuits of working memory (Li, Christ, & Cowan, 2014).

Recently, evidence has been provided that the effects of music on language skills also may be supported by a distinct neural system for *processing of structured auditory regularities* (Strait et al., 2011). Koelsch et al. (2002) were among the first to demonstrate that processing chord sequences activates the areas of Broca and Wernicke and the temporal gyrus, comprising a cortical network that has been identified as domain-specific for language processing. Comparative neuroimaging and electro/magnetoencephalographic studies have confirmed that discrete structured elements, arranged in rhythmic sequences characterizing both music and language, are processed by a common neural system in the brain (Koelsch, Rohrmeier, Torrecuso, & Jentschke, 2013; Patel, 2003), largely engaging the neural structures of implicit memory (Ettlinger, Margulis, & Wong, 2011; Ullman, 2001), in contrast to explicit attentional control in working memory.

Within the understanding that musical information is processed both explicitly and implicitly in the phonological loop, one objective of the present study was to investigate if brief exposure to music might facilitate subsequent processing of verbal material. Following the approach of Mammarella et al. (2007), we targeted two verbal functions, verbal working memory and phonologically-cued semantic retrieval from long-term memory as represented by the forward digit span test (F-DST; Wechsler, 1997) and word fluency test (WFT; Borkowski, Benton, & Spreen, 1967). Accordingly, we used the F-DST to reflect mainly phonological loop capacity, whereas the WFT was applied to impose stronger demands on central executive components of working memory, such as active search in long-term memory, verbal response production, response monitoring, and inhibition of irrelevant candidates (Mammarella et al., 2007). Also, the phonemic rather than the semantic version of the WFT was applied to avoid confounding with semantic memory problems (Henry, Crawford, & Phillips, 2004) and to better highlight the interaction between music experience and the phonological loop. Thus, the choice of cognitive tests in the present study aimed to target the phonological loop of working memory. We expected an improvement for both verbal tasks after exposure to music. However, since the WFT would presumably impose a stronger challenge to executive control functions, we further expected that the immediate effects of musical experience might differ between F-DST and WFT in case of a specific and distinct role of executive control functions for the immediate effects of music on verbal memory.

To further distinguish the role of central executive, we studied groups of younger and older healthy adults. It has been consistently reported that executive control, working memory and attentional functions decline with aging (Grady, 1998; Grivol & Hage, 2011; Reuter-Lorenz, 2002). Hence, we hypothesized that if musical experience affects verbal cognition via active control mechanisms, the outcome would differ between younger and older participants, which would additionally depend on the task, F-DST or WFT. Although previous studies (Mammarella et al., 2007) have observed improvement on both tests after exposure to music in older individuals, open methodological issues have not allowed firm conclusions. Moreover, semantic fluency is also deteriorated with increasing age in humans (Grivol & Hage, 2011). Whereas long-lasting positive effects of musical training in aging are well documented (e.g., Bidelman & Alain, 2015; Moussard, Bermudez, Alain, Tays, & Moreno, 2016), it has not been clarified so far if brief exposure to music may produce fast modulations in individuals with declining verbal memory functions. Addressing this question is also of relevance for practical and therapeutic applications in the elderly.

To account for the modulation by the system for implicit processing of acoustic regularities, the present study manipulated the stimulation musical material. The stimulation material was selected to represent a high index of periodicity and repetitive structure, and to potentiate subsequent verbal processing (Ettlinger et al., 2011; Koelsch et al., 2013; Patel, 2003; Ullman, 2001). Excerpts by three different composers (Vivaldi, Mozart and Glass) were chosen to allow variations across baroque, classical and contemporary minimalist music, while keeping similarity in tempo and complexity. Among those compositions, the excerpt of Glass represented a dominating periodicity and repetitive structure. We hypothesized that if implicit processing of repetitive sequences serves to prime verbal functions (Carrus, Pearce, & Bhattacharya, 2013; Ullman, 2001), the post-listening performance would distinguish the Glass composition. The compositions of Mozart and Vivaldi were selected to target established but still controversial research.

Finally, the present study aimed at elucidating the role of non-specific factors such as arousal and emotional activation. The effect which specific musical pieces have on human behavior has been explained as a consequence of their impact on positive mood and arousal (Nantais & Schellenberg, 1999; Panksepp & Bernatzky, 2002; Thompson et al., 2001). It is accepted that listening to music shifts arousal (degree of physiological activation), emotional activation (enjoyment) and mood (long-lasting emotional tone), which in turn may influence performance on a variety of cognitive tasks (Thompson et al., 2001). To account for the arousal-and-mood hypothesis (Thompson et al., 2001), we applied a score of music preference. There are scarce research protocols which try to use music preferences as an index of emotional influences on cognitive performance (Giannouli, Tsolaki, & Kargopoulos, 2010; McKelvie & Low, 2002; Nantais & Schellenberg, 1999). Moreover, there is no research having used proved unfamiliar excerpts to the listeners when testing whether there is a beneficial effect of music on memory tasks. It is not clear from previous similar studies whether any positive influences are derived from emotional involvement typically associated with familiar music. The high familiarity of the music excerpts typically used may have induced positive mood and emotional involvement thus favoring generally better performance (Mammarella et al., 2007). Therefore, familiarity with the excerpts was an exclusion criterion in the current study, and online music preference was evaluated to account for emotional activations, while exposure to silence contrasted with multiple unknown excerpts served as a control for the effects of arousal. In addition, to avoid possible longstanding influences of music expertise (Moreno & Bidelman, 2014), only non-musicians participated.

Thus, to elucidate the contribution of working memory, arousal and emotional activations to post-music modulations of verbal cognition, the present study compared the effects of entirely novel music listening conditions with different levels of periodicity on verbal memory functions between younger and older healthy non-musicians.

Method

Participants

Two hundred and forty young adults (mean age = 28.63 years, *SD* = 9.02; mean duration of education = 14.39 years, *SD* = 1.64) and 227 older community dwelling adults (mean age = 72.23 years, *SD* = 6.57; mean duration of education = 7.81 years, *SD* = 3.93) from Northern Greece participated in this study in which we adopted a repeated-measures design, with music condition (listening to pieces of Mozart, Vivaldi, Glass, and no-music condition) as within-subjects variable. The young adults had no past or current psychiatric diagnosis or cognitive deficits. Although some older adults had been following medication related to heart problems, they had no official diagnosis of a cognitive deficit and had scored above 27 points on the Greek version of the Mini Mental State Examination (MMSE) to exclude dementia. Exclusion criteria for both groups of younger and older participants were a history of psychiatric, neurological or substance abuse-dependence, a history of head injury or any other medical condition (including significant perceptual deficits such as visual and/or hearing impairments not corrected sufficiently by aids) that might affect neuropsychological performance, and non-native speakers of the Greek language. All participants were non-musicians and the current occupation of the younger adults was not related to music, as well as the previous occupation for the group of the older adults who were retired. All participants gave informed consent and were treated according to the Declaration of Helsinki.

Stimuli

The participants were unfamiliar with the selected approximately 10-minute music excerpts that were used in the experiment: (1) Mozart's Sonata for Two Pianos in D Major (Allegro con spirito, K. 448), (2) Vivaldi's harpsichord concerto, Op. 4 n.10, (3) Glass's Music with Changing Parts, and (4) a silence condition without any recorded acoustic stimulus. The three music excerpts had to be unknown to the participants in order to reduce the possibility of previous emotional or other experiences that may affect performance on the cognitive tasks. The music compositions did not differ in their rhythmic tempo, but they differed in tonality, music style and in the performing musical instruments. The choice of this specific Mozart's sonata was made based on the plethora of studies claiming a beneficial Mozart effect on various aspects of cognition (Schellenberg, 2012); the choice of Vivaldi's music in general was made based on previous findings that support Vivaldi's music beneficial influence specifically on working memory performance (Mammarella et al., 2007); Glass's excerpt was chosen based on preliminary unpublished research concerning verbal working memory by the first author; while the no-music condition was included as it is used in all published research as a control condition. The music conditions (Mozart, Vivaldi, Glass, and no-music condition) were counterbalanced across groups of participants with a Latin square design and based on that the sample size was determined accordingly.

Procedure

All participants were tested in one session in different groups of 10 participants, on average for a total of two hours. At first they filled out a demographic questionnaire, and then they were given a general oral explanation of the tasks that they would be asked to perform later immediately after the listening conditions. The different groups of participants before the beginning of the main experiment had the opportunity to adapt the volume of pre-recorded noise with verbal instructions to a level that would allow them all as a team to listen clearly in the testing room.

Between each of the four conditions there was a short break. After each of the four conditions (and during the breaks), each participant performed the two cognitive tests (phonologically-cued word fluency test and forward digit span task). In this way, each participant has four measures for the first test and four measures for the second test.

As argued in the introduction, these two tests were chosen as both of them are assumed to rely on the phonological and executive components of working memory (Baddeley, 1986). For the purposes of this study, we followed exactly the methodology as adopted in previous research by Mammarella et al. (2007), where the same two tests were used to reflect verbal memory. Also, both tests are among the few standardized neuropsychological tests in use in Greece.

Half of the participants were examined first with the forward digit span task for all four music conditions, and then with the phonological fluency test. The other half of the participants were given the same tests in a reverse order and they were examined first with the phonological fluency test for all music conditions and then with the forward digit span task. Data for the working memory performance for the above tests was collected via paper-and-pencil.

The examination material for the forward versions of the digit span was a series of improvised groups which consisted of numbers from 2 to 14 digits, which were read at a rate of one digit per second. The participants had to write down their answers for two sets of numbers per digit-length. In the statistical analyses in order to claim that a digit-length was achieved, at least one of the two trials had to be correct, and scoring by the examiner ended when a participant was incorrect on two trials of the same length. Participants were required to write down the sequences in the same order following the four listening conditions. A practice sequence of two digits was given for each task before the experiment started.

In addition to that, a version of the word fluency test was also administered in which the participants were required to produce in written form as many words as possible beginning with a specified letter from the Greek alphabet (e.g., participants were asked to generate as many different words as possible beginning with the Greek letters chi, sigma, alpha, pi; excluding proper nouns and variations of the same word), in a period of five minutes (phonemic fluency). The phonological condition of the word fluency test imposes strong demands on executive functioning and on phonological working memory, and it was chosen for the present experiment because it includes executive components of working memory such as active search in long-term memory by means of phonemic cues, verbal response production, keeping track of the responses already given, and inhibition of irrelevant candidates.

Finally, at the end of the experiment all participants were asked to indicate which of the four conditions was their favorite and whether they had listened to the four excerpts of music previously. Twelve participants were excluded from the study, because they were familiar with at least one of the music excerpts. Due to incompleteness of records, an additional 19 participants were excluded. The final number of participants is presented in Table 1.

Statistical analysis

Measures of the Forward Digit Span Test (F-DST) and Word Fluency Test (WFT) were subjected to analysis of variance with repeated measures (ANOVA) with two between-subjects variables, Age (younger vs. older) and excerpt Preference with four levels (Mozart vs. Vivaldi vs. Glass vs. Silence) and one within-subjects variable, Music Condition with four levels (MC, Mozart vs. Vivaldi vs. Glass vs. Silence). Because the order of tests was counterbalanced across subjects, factor order was not included in the general analysis. In additional analyses, it was tested if effects of music condition were persistent or could be abolished by intermittent activity induced by a preceding memory task (task-order effect). Greenhouse-Geisser correction was applied to within-subjects factors with more than two levels. Original *df* and corrected *p* values are reported.

Results

The distribution of subjects according to preference of musical excerpts is presented in Table 1. The two age groups did not differ with respect to distribution of musical preference, $\chi^2(3, N = 448) = 6.3$, $p = .1$. No correlation existed between F-DST and WFT scores in the whole sample, $r = -0.07$, $p = .2$, in the group of younger adults, $r = -0.05$, $p > .4$, or in the group of older adults, $r = -0.09$, $p > .2$, confirming the functional specificity of the two tests.

Forward Digit Span Test

Age effect. Figure 1 (left) shows that young adults manifested significantly higher F-DST scores compared to older adults, $F(1, 440) = 6.7$, $p = .01$.

Preference effect. Interestingly, as depicted in Figure 2 (left), individuals with expressed preference for the Vivaldi excerpt had significantly better results on the F-DST compared to individuals with a preference for Mozart, but this was only valid for young subjects (Age × Preference), $F(3, 447) = 3.8$, $p = .01$; preference effect in younger adults, $F(3, 230) = 5.9$, $p = .001$; in older adults, $F(3, 210) = 0.4$, $p > .7$.

Musical condition effect. Figure 3 (left) shows that following Vivaldi, a decrease in F-DST performance occurred, $F(3, 1320) = 9.2$, $p < .001$, which was not modulated by individual preference for excerpts (MC × Preference), $F(9, 1320) = 1.7$, $p = .1$, and did not depend on subject's age (Age × MC), $F(3, 1320) = 0.88$, $p = .4$; MC effect in younger adults, $F(3, 690) = 3.4$, $p = .03$; MC effect in older adults, $F(3, 630) = 6.3$, $p = .001$. To explore if this Vivaldi effect was sustainable over time or if it was induced by the immediate music experience, analyses were performed separately for the sub-groups of individuals who performed the F-DST before and after the WFT. The impairing effect of the Vivaldi excerpt on working memory was confirmed for both test sequences (MC effect in F-DST-first), $F(3, 666) = 3.2$, $p = .04$; (MC effect in F-DST-second), $F(3, 630) = 5.2$, $p = .002$, being stronger in younger than older adults when the F-DST followed WFT (MC × Age), $F(3, 630) = 3.5$, $p = .02$.

Phonologically-cued Word Fluency Test

Age effect. Figure 1 (right) demonstrates that, as expected, word fluency was overall substantially better in young than older subjects, $F(1, 440) = 451.5$, $p < .001$.

Preference effect. Notably, as Figure 2 (right) demonstrates, word fluency was better in individuals who had preference for music vs. silence, $F(3, 440) = 2.5$, $p = .05$. Paired *t*-tests yielded significant differences between preference for silence and preference for any music condition ($p < .01$, Bonferroni corrected). This effect was stable across age groups (Preference × Age), $F(3, 440) = .9$, $p > .4$.

Musical condition effect. Most interestingly, a significant MC effect, $F(3, 1320) = 14.3$, $p < .001$, revealed that word fluency was significantly improved following Vivaldi as compared to other music conditions ($p < .001$ for paired *t*-test comparisons), whereas it was impaired following Mozart as compared to other conditions ($p < .001$ for paired *t*-test comparisons) – Figure 3 (right). As indicated by the significant Age × MC interaction, $F(3, 1320) = 4.9$, $p = .005$, the improving Vivaldi and impairing Mozart effects dominated in the group of young subjects, $F(3, 690) = 7.7$, $p = .001$, $p < .001$ for paired *t*-tests comparing post-Vivaldi with post-other conditions performance; $p < .01$ for post-Mozart comparisons in young adults) – Figure 4 (left). In the group of older subjects, only the impairing Mozart effect was found, $F(3, 630) = 14.7$, $p < .001$, $p < .01$ for paired *t*-test comparisons between post-Mozart and post-other conditions performance in older participants – Figure 4 (right). Figure 4 further demonstrates that these excerpt-specific effects on phonological word fluency did not depend on musical preference. It is to be noted that the specific effects of Vivaldi and Mozart in the two age groups were confirmed for the samples performing the word fluency test before F-DST, $F(3, 630) = 2.4$, $p < .05$; (MC ×

Table 1. Number and distribution of participants according to age and musical preferences.

	Mozart	Vivaldi	Glass	Silence	Total
Young	63 (26.9%)	98 (41.9%)	40 (17.1%)	33 (14.1%)	234
Old	54 (25.3%)	70 (32.7%)	48 (22.4%)	42 (19.6%)	214
All participants	117 (26.2%)	168 (37.5%)	88 (19.6%)	75 (16.7%)	448

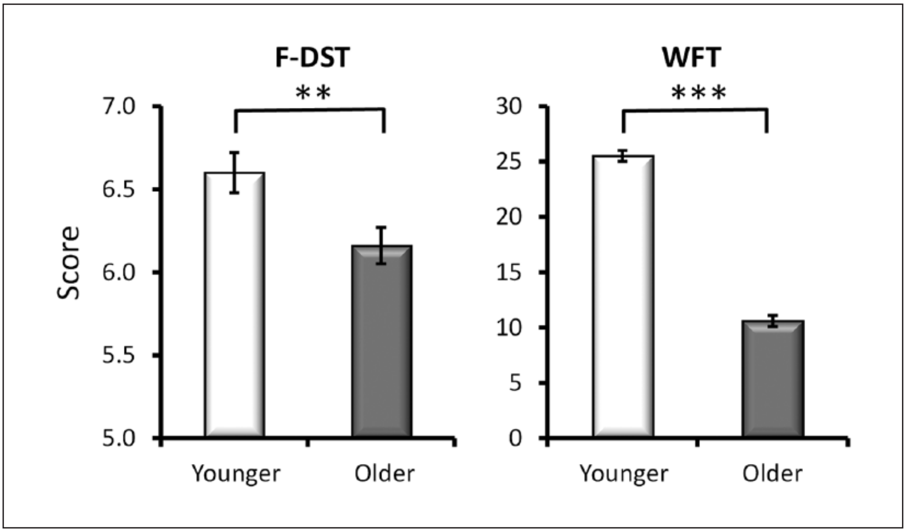

Figure 1. Age group means of F-DST (left) and WFT (right) scores. Error bars present standard error of mean. $^{**}p < .01$; $^{***}p < .001$ for between-group comparisons.

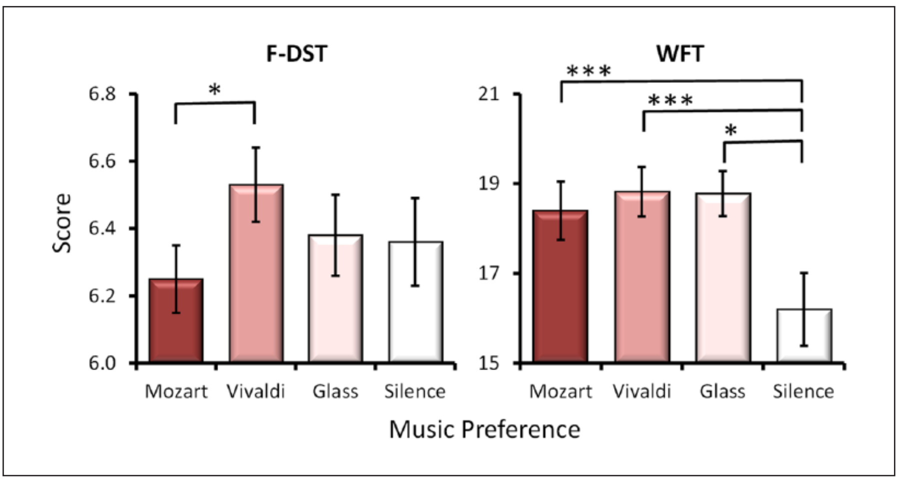

Figure 2. Group means of F-DST (left) and WFT (right) scores according to music preference. Error bars present standard error of mean. $^{*}p < .05$; $^{***}p < .001$ for between-group comparisons.

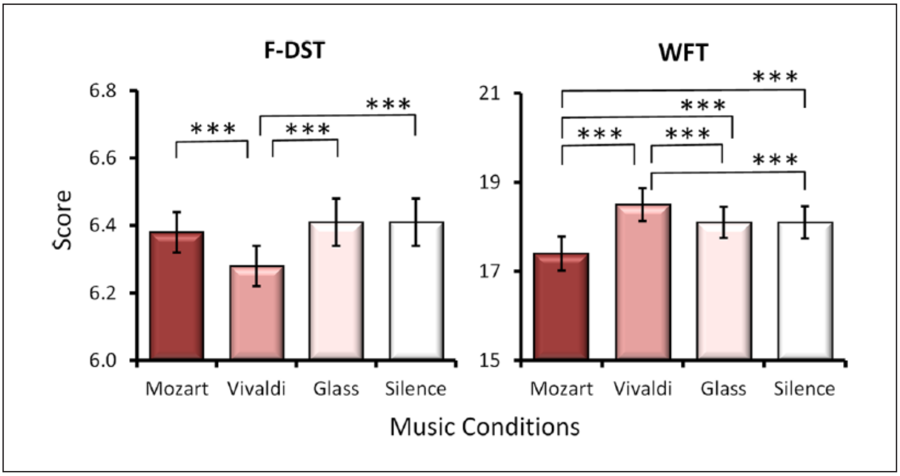

Figure 3. Group means of F-DST (left) and WFT (right) scores following music conditions. Error bars present standard error of mean. $^{***}p < .001$ for between-group comparisons.

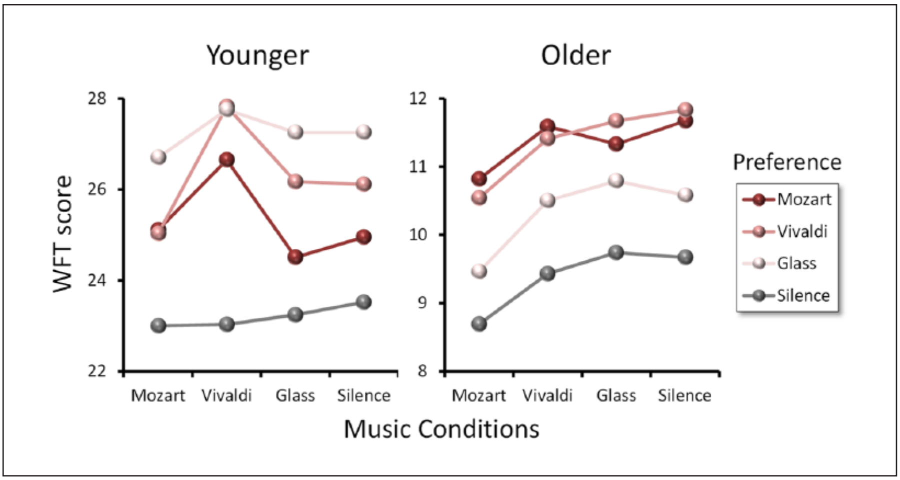

Figure 4. Group means of WFT scores in younger (left) and older (right) participants following different music conditions according to music preference.

Age), $F(3, 630) = 2.8$, $p = .05$, and after F-DST, $F(3, 660) = 11.8$, $p = .001$; (MC × Age), $F(3, 660) = 3.6$, $p = .02$.

Discussion

The present study investigated the effects of brief exposure to music on subsequent verbal memory functions in young and older adults. The major aim was to clarify the roles of working memory components, implicit processing of auditory regularities, arousal and emotional activation in mediating transient changes of verbal memory efficiency after passive listening to music. A novel methodological advantage was the attempt to control for the mediating effects of emotional and arousal activations by using multiple novel (unknown) excerpts by different composers from the Western tonal musical tradition (Mozart, Vivaldi, and Glass) and contrast their effects to those following silence, along with scoring online music preference in non-musicians.

Major results showed that brief exposure to music had no beneficial effects on verbal working memory as indicated by the lack of post-music enhancement of F-DST scores. Moreover, we detected an excerpt- or composer-specific deterioration of verbal working memory (Vivaldi in our case) in the two age groups. In contrast, brief exposure to music induced bi-directional changes in phonologically-cued word fluency, again depending on the excerpt/composer. WFT scores were enhanced after Vivaldi's composition in young adults, whereas they were significantly lowered after Mozart's composition in the two age groups.

These results are not fully consistent with existing reports about transient cognitive benefits of music (Riby, 2013). Until now only three studies with healthy elders compared the effects of listening to music excerpts with high tempo and in the major mode with no-music conditions on phonologically-cued word fluency (Mammarella et al., 2007; Thompson, Moulin, Hayre, & Jones, 2005), on phonological working memory (Mammarella et al., 2007), and on recognition memory (Ferreri et al., 2014). They all reported a positive effect of different background music excerpts, which was expressed as an enhancement of the performance of elder participants' cognitive abilities. Also, we could not support the beneficial Mozart effect in young adults (Jaušovec & Habe, 2005), or the improvement of general cognitive performance after listening to Mozart's K.448 sonata in healthy and non-healthy elders (Cacciafesta et al., 2010). Thus, our results are consistent with a substantial body of literature which argues that there is little evidence for a specific performance-enhancing effect of Mozart's music (or other classical music; e.g., Steele, Ball, & Runk, 1997; Chabris, 1999; Pietschnig et al., 2010; Verrusio et al., 2015). Moreover, the investigation of large samples in a balanced and controlled experimental design with multiple music excerpts, as applied in the present study, revealed that passive listening to music might even induce a transient impairment of verbal memory functions in non-musicians. The employment of multiple novel compositions further helped to elucidate the exclusive and unique influence that a specific music excerpt might exert on subsequent verbal memory, in terms of possible priming or inhibition, types of verbal memory operations which are affected, and individual differences determined by the age.

Arousal and emotions

The currently detected negative or lacking effects of preceding music on verbal working memory may not be due to differential arousal or emotional activations since (a) working memory performance was lower specifically after Vivaldi but not after other music excerpts as could be expected in the case of critical arousal influences, (b) F-DST scores following no-music (silence) did not differ from those following Mozart and Glass, (c) working memory deterioration after listening to the Vivaldi excerpt was not associated with individual preference for any musical piece, but rather occurred independently of music preference and related enjoyment (Cabanac, 1992, 2010; Panksepp, 1995; Sacks, 2006), (d) all music excerpts were novel, so that previous knowledge or familiarity might not have triggered specific emotional reactions, and (e) all participants were non-musicians, so that priming from existing musical expertise was avoided (Bidelman et al., 2014; Moreno & Bidelman, 2014; Patel, 2014; Zuk et al., 2014). The same arguments apply to the modulations of semantic fluency after exposure to music where silence alone did not differ from music conditions, nor was music preference specifically linked to positive or negative effects. Thus, the present results do not seem to provide a direct support to the arousal-and-mood hypothesis (Thompson et al., 2001). It should be noted, however, that objective physiological signals of cortical activation or psychophysiological indices of arousal/emotional reactions were not recorded in the present study to allow a direct assessment of physiological states.

Processing of structured auditory regularities

Notably, according to the present findings, music with dominating repetitive structure (Glass, in our case) did not manifest peculiar post-listening effects on subsequent verbal memory functions, since both F-DST and WFT scores did not distinguish Glass from the silence condition. This observation shows that preceding processing of structured auditory regularities in music sequences (Ettlinger et al., 2011; Koelsch et al., 2013), as represented by Glass excerpts in our study, may not influence subsequent verbal functions. Also, it implies that a short-lasting pre-activation of the neural circuit for implicit regularity processing (Koelsch et al., 2013; Ullman, 2001) as applied here, is not sufficient or efficient to prime attentional operations on non-rhythmic verbal material or to promote phonologically-cued semantic associations. Hence, the associations between regularity processing in music and language may emerge after neuroplastic changes in overlapping auditory networks (Patel, 2014; Strait et al., 2011). This suggestion is fully consistent with the current observation that individuals who preferred music to silence, possibly reflecting a trait-dependent interest or affinity to listening to music, had significantly better word fluency scores. It cannot be excluded, however, that a dominating repetitive structure in music may specifically promote the capacity for rhyming or producing structured verbalization where rhythmic regularities are emphasized.

Working memory components

In the present study, two verbal memory tests and two age groups were used in an attempt to explore if brief exposure to music would tackle differentially executive control operations and operations in the phonological loop. The results of opposite effects of Vivaldi on F-DST and WFT and different aging effects on WFT following Vivaldi provide some support to the notion that the central executive component of working memory (Baddeley, 1986) is indeed involved differently from the phonological loop, even in passive listening conditions. However, interpretations of these observations should certainly consider the fact that we found an impairment rather than improvement of verbal memory, and the effects strongly depended on the specific musical composition.

How can we explain the Vivaldi-specific impairment of verbal working memory and improvement of phonologically-cued semantic memory immediately after listening? The temporary decrease of WM performance can be referenced to functional factors that have been established to impair WM. One critical factor is pro-active interference whereby a simultaneous processing of distracting information hampers ongoing operations (Lustig & Hasher, 2002; Lustig, May, & Hasher, 2001). Pro-active interference has been demonstrated for music by Zhu et al. (2008) who reported that a simultaneous listening to Mozart music impaired voluntary attention. Another functional factor is inferred by evidence on the existence of residual activations in the brain. Research of resting state networks has demonstrated that the activations of functionally engaged regions are preserved long after the task/experience having induced them is no longer performed (e.g., Bressler & Menon, 2010; Sami, Robertson, & Miall, 2014). Music experience has been reported to recruit not only auditory temporal but also frontal and parietal cortical regions engaged in WM (Caplan & Waters, 1999; Koelsch & Friederici, 2003; Maess, Koelsch, Gunter, & Friederici, 2001; Tillmann, Janata, & Bharucha, 2003). We therefore suggest that post-listening impairing effects of exposure to music may arise from pro-active interference by residual activations in both the phonological loop and central executive circuits of working memory.

Within this notion, prolonged maintenance of residual activations in executive control circuits may mimic the "dual task effect" reported during listening to music (Zhu et al., 2008) and may reduce attentional capacity for various subsequent tasks. This can explain performance impairment of both F-DST and WFT scores found here. Capacity may also be reduced for passive processing in the phonological loop. A recognized perceptual phenomenon in music experience supports this suggestion. Music can induce automatic involuntary rehearsal in the form of spontaneous uncontrollable melody production. This form of perseveration, also known as earworm, brainworm, sticky music or stuck song syndrome, is the continuous repetition of a piece of music through a person's mind after it is no longer played (Beaman & Williams, 2010; Sacks, 2007). Therefore, it is also possible that the phonological loop remains preoccupied after exposure to specific music excerpts. Intrusive songs-music returns during low cognitive load activities, and overloading and challenging cognitive activities may increase intrusive song frequency (Hyman et al., 2013), further implying that interacting residuals in both the phonological and executive control networks concurrently modify subsequent verbal functions. In this line, the present results additionally imply that residuals might not only block, but, in contrast, might facilitate actual processing networks. The improvement of phonologically-cued semantic retrieval in young adults after listening to Vivaldi found here points to a facilitated access to semantics via pre-activated phonological or attentional cues. Likewise, Mammarella et al. (2007) propose that the positive effects of music may be based on the stimulation of "increased attention towards auditory stimuli and connections between items as well as cues to guide memory search (e.g. phonemic fluency) at encoding" (p. 398). However, it remains to be established by future studies exactly how the components of WM (executive control, phonological, and visuospatial loops) are pre-activated by passive listening to music, and how such pre-activations may interact to either prime or inhibit subsequent processing in specific loops. We assume that clarifying these interactions may shed light on existing controversies about the Mozart effect and related observations in music research.

Music features

The present results show that the currently used excerpt of Vivaldi appears to have inhibited verbal working memory on one side, and to have promoted semantic retrieval on the other side. Mozart's excerpt used here, however, specifically inhibited the phonological-semantic circuitry. Thus, specific excerpt (or composer) music features are evinced as unique for subsequent cognition. Any attempt to explain these excerpt-(composer)-specific effects leads to the debate whether characteristics of the music compositions' micro- and macro-morphological structure such as periodically repetitive patterns from baroque composers (e.g., Vivaldi), to classical music (coming from famous composers such as Mozart), to the minimalist contemporary music (as represented by Philip Glass, (Giannouli et al., 2010), or melodic form (Rauscher & Shaw, 1998; Wallace, 1994), tempo, mode, or hierarchical structure (local sequences nested in long-distance sequences, Koelsch et al., 2013) may be the critical factors. The three music excerpts used here have a high index of periodicity following repetitive structures and a tonal center, are similar in tempo, and in the level of complexity. If the melodic form of Vivaldi's excerpt is more able to be extracted, it may have been more efficient in engaging phonological and attentional circuits of verbal working memory. Currently, we do not have a satisfactory explanation of the observation that Vivaldi's excerpt induced opposite effects on F-DST and WFT scores, whereas Mozart's excerpt induced a transient impairment of semantic fluency. Nor can we know exactly why verbal working memory was predicted by individual music preference specifically to Vivaldi and Mozart (Figure 2), irrespective of preceding listening conditions. Future studies are needed to analyze precisely music features and to try to identify their possible specific functions in perception and cognition. As an intriguing yet hard to prove note, it cannot be excluded that composer-specific music contains hard-to-identify elements in musical micro-and macro-structure reflecting the composer's personality or mentality. For Mozart, for example, a psychiatric disturbance has been suspected (Monaco, Servo, & Cavanna, 2009; Schmitt & Falkai, 2014), which may have penetrated to shape the repetitions of the main melodies/melodic lines in his compositions (Hughes, 2002).

Individual differences

According to the results, individual preference for music perception as opposed to preference for no music experience was associated with superior verbal fluency, irrespective of preceding exposure to music. These observations confirm indirectly previously established positive associations between musicianship and cognitive abilities (Moreno & Bidelman, 2014) linked to neuroplasticity. It is notable that listening to the Vivaldi excerpt led to a transient deterioration of WM, whereas individual preference for the same Vivaldi excerpt, in contrast, predicted an overall superior WM performance, without interaction between music listening and music preference factors. To address this paradox we suggest that residuals induced by Vivaldi music act to inhibit through interference subsequent working memory operations, but at the same time, prolonged maintenance of residuals may act as internal stimulators of working memory in some individuals. With regard to aging effects, we could not detect any beneficial effects of brief exposure to music in older adults. On the contrary, both verbal working and semantic memories were impaired, raising a note of precaution for the older population. Again, however, unique music conditions need to be accounted for.

Limitations of the study and open questions

Although the sample size of the present study is large, one of the limitations of this study is that the findings are valid only for this specific experimental design. Experimental manipulation with a variety of cognitive tests would be needed (a) to distinguish the components of working memory, (b) to compare more directly the involvement of the phonological and visuospatial loops, and (c) to contrast them with the central executive component. This latter issue specifically needs clarification since the word fluency test used in the present study is claimed to be hybrid (Shao, Janse, Visser, & Meyer, 2014), and the involvement of executive control and phonological loops in the F-DST and WFT has not been precisely distinguished (Strauss, Sherman, & Spreen, 2006). Also, arousal, emotional and cognitive reactions to music listening need to be verified with objective measures like electroencephalography, event-related potentials, functional imaging, etc., to prove the specific and differential involvement of working memory components. Future research should further investigate whether passive music listening of the same music excerpts or of other classic composers belonging to different music eras and styles can influence different or the same cognitive functions. Finally, a more detailed musicological analysis of the characteristics of the specific music excerpts could shed more light on the explanations regarding cognitive performance.

Conclusions

Brief exposure to music has no immediate beneficial effect on verbal working memory, with even a transient impairment found following Vivaldi's excerpt. In contrast, Vivaldi's music induced a marked transient enhancement of phonologically-cued word fluency, but only in young adults. Since direct influences by arousal, emotional activations, and previous music experience do not appear to contribute critically to these transient modulations in verbal cognition, the results suggest that the musical experience induces residual activations which interfere with verbal processing systems. Depending on music structure and characteristics expressed in different excerpts and composers, residual activations may have the potency to either facilitate (word fluency) or limit (working memory capacity) ongoing verbal processing. Notably, the results further suggest that the transient reduction of working memory capacity by preceding music may act as an internal enhancer of working memory in the long run in both younger and older individuals.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Funding for this research was provided by the postdoctoral research fellowship "In memory of Maria Zaousi" State Scholarships Foundation IKY, for the academic year 2015–2016 to VG.

References

Baddeley, A. (1986). *Working memory*. Oxford, UK: Oxford University Press.

Beaman, C. P., & Williams, T. I. (2010). Earworms (stuck song syndrome): Towards a natural history of intrusive thoughts. *British Journal of Psychology*, *101*(4), 637–653.

Bidelman, G. M., & Alain, C. (2015). Musical training orchestrates coordinated neuroplasticity in auditory brainstem and cortex to counteract age-related declines in categorical vowel perception. *The Journal of Neuroscience*, *35*(3), 1240–1249.

Bidelman, G. M., Weiss, M. W., Moreno, S., & Alain, C. (2014). Coordinated plasticity in brainstem and auditory cortex contributes to enhanced categorical speech perception in musicians. *European Journal of Neuroscience*, *40*(4), 2662–2673.

Borkowski, J. G., Benton, A. L., & Spreen, O. (1967). Word fluency and brain damage. *Neuropsychologia*, *5*(2), 135–140.

Bressler, S. L., & Menon, V. (2010). Large-scale brain networks in cognition: Emerging methods and principles. *Trends in Cognitive Sciences*, *14*(6), 277–290.

Cabanac, M. (1992). Pleasure: The common currency. *Journal of Theoretical Biology*, *155*(2), 173–200.

Cabanac, M. (2010). *The fifth influence: The dialectics of pleasure*. Bloomington, IN: iUniverse.

Cacciafesta, M., Ettorre, E., Amici, A., Cicconetti, P., Martinelli, V., Linguanti, A. E. E. A., ... Marigliano, V. (2010). New frontiers of cognitive rehabilitation in geriatric age: The Mozart Effect (ME). *Archives of Gerontology and Geriatrics*, *51*(3), e79–e82.

Chabris, C. (1999). Prelude or requiem for the "Mozart effect"? *Nature*, *400*, 826–827.

Caplan, D., & Waters, G. S. (1999). Verbal working memory and sentence comprehension. *Behavioral and Brain Sciences*, *22*(1), 77–94.

Carpentier, S., Moreno, S., & McIntosh, A. R. (2016). Short-term music training enhances complex, distributed neural communication during music and linguistic tasks. *Journal of Cognitive Neuroscience*, *28*, 1603–1612.

Carrus, E., Pearce, M. T., & Bhattacharya, J. (2013). Melodic pitch expectation interacts with neural responses to syntactic but not semantic violations. *Cortex*, *49*(8), 2186–2200.

Clayton, K. K., Swaminathan, J., Yazdanbakhsh, A., Zuk, J., Patel, A. D., & Kidd, G., Jr. (2016). Executive function, visual attention and the cocktail party problem in musicians and non-musicians. *PloS One*, *11*(7), e0157638.

Coull, J. T. (1998). Neural correlates of attention and arousal: Insights from electrophysiology, functional neuroimaging and psychopharmacology. *Progress in Neurobiology, 55*(4), 343–361.

Ettlinger, M., Margulis, E. H., & Wong, P. C. (2011). Implicit memory in music and language: The relationship between music and language. *Frontiers in Psychology, 2*, 2159.

Ferreri, L., Bigand, E., Bard, P., & Bugaiska, A. (2015). The influence of music on prefrontal cortex during episodic encoding and retrieval of verbal information: A multichannel fNIRS study. *Behavioural Neurology*, e707625.

Ferreri, L., Bigand, E., Perrey, S., Muthalib, M., Bard, P., & Bugaiska, A. (2014). Less effort, better results: How does music act on prefrontal cortex in older adults during verbal encoding? An fNIRS study. *Frontiers in Human Neuroscience, 8*, 301.

Giannouli, V., Tsolaki, M., & Kargopoulos, P. (2010). The influence of Mozart's and Beethoven's music on reverse mnemonic recall tasks. *Psychiatrike=Psychiatriki, 21*(1), 60–67.

Grady, C. L. (1998). Brain imaging and age-related changes in cognition. *Experimental Gerontology, 33*(7), 661–673.

Grivol, M. A., & Hage, S. R. D. V. (2011). Phonological working memory: A comparative study between different age groups. *Jornal da Sociedade Brasileira de Fonoaudiologia, 23*(3), 245–251.

Henry, J. D., Crawford, J. R., & Phillips, L. H. (2004). Verbal fluency performance in dementia of the Alzheimer's type: A meta-analysis. *Neuropsychologia, 42*(9), 1212–1222.

Hughes, J. R. (2002). The Mozart effect: Additional data. *Epilepsy & Behavior, 3*(2), 182–184.

Hyman, I. E., Burland, N. K., Duskin, H. M., Cook, M. C., Roy, C. M., McGrath, J. C., & Roundhill, R. F. (2013). Going Gaga: Investigating, creating, and manipulating the song stuck in my head. *Applied Cognitive Psychology, 27*(2), 204–215.

Jaušovec, N., & Habe, K. (2004). The influence of auditory background stimulation (Mozart's sonata K. 448) on visual brain activity. *International Journal of Psychophysiology, 51*(3), 261–271.

Jaušovec, N., & Habe, K. (2005). The influence of Mozart's sonata K. 448 on brain activity during the performance of spatial rotation and numerical tasks. *Brain Topography, 17*(4), 207–218.

Koelsch, S., & Friederici, A. D. (2003). Toward the neural basis of processing structure in music. *Annals of the New York Academy of Sciences, 999*(1), 15–28.

Koelsch, S., Gunter, T. C., Cramon, D. Y. V., Zysset, S., Lohmann, G., & Friederici, A. D. (2002). Bach speaks: A cortical "language-network" serves the processing of music. *Neuroimage, 17*(2), 956–966.

Koelsch, S., Rohrmeier, M., Torrecuso, R., & Jentschke, S. (2013). Processing of hierarchical syntactic structure in music. *Proceedings of the National Academy of Sciences, 110*(38), 15443–15448.

Li, D., Christ, S. E., & Cowan, N. (2014). Domain-general and domain-specific functional networks in working memory. *Neuroimage, 102*(Pt. 2), 646–656.

Lustig, C., & Hasher, L. (2002). Working memory span: The effect of prior learning. *The American Journal of Psychology, 115*(1), 89–101.

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General, 130*(2), 199–207.

Maess, B., Koelsch, S., Gunter, T. C., & Friederici, A. D. (2001). Musical syntax is processed in Broca's area: An MEG study. *Nature Neuroscience, 4*(5), 540–545.

Mammarella, N., Fairfield, B., & Cornoldi, C. (2007). Does music enhance cognitive performance in healthy older adults? The Vivaldi effect. *Aging Clinical and Experimental Research, 19*(5), 394–399.

McKelvie, P., & Low, J. (2002). Listening to Mozart does not improve children's spatial ability: Final curtains for the Mozart effect. *British Journal of Developmental Psychology, 20*(2), 241–258.

Monaco, F., Servo, S., & Cavanna, A. E. (2009). Famous people with Gilles de la Tourette syndrome? *Journal of Psychosomatic Research, 67*(6), 485–490.

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S. L., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: More evidence for brain plasticity. *Cerebral Cortex, 19*(3), 712–723.

Moreno, S., & Bidelman, G. M. (2014). Examining neural plasticity and cognitive benefit through the unique lens of musical training. *Hearing Research, 308*, 84–97.

Moussard, A., Bermudez, P., Alain, C., Tays, W., & Moreno, S. (2016). Life-long music practice and executive control in older adults: An event-related potential study. *Brain Research, 1642*, 146–153.

Nantais, K. M., & Schellenberg, E. G. (1999). The Mozart effect: An artifact of preference. *Psychological Science*, *10*(4), 370–373.

Panksepp, J. (1995). The emotional sources of "chills" induced by music. *Music Perception*, *13*(2), 171–207.

Panksepp, J., & Bernatzky, G. (2002). Emotional sounds and the brain: The neuro-affective foundations of musical appreciation. *Behavioural Processes*, *60*(2), 133–155.

Patel, A. D. (2003). Language, music, syntax and the brain. *Nature Neuroscience*, *6*(7), 674–681.

Patel, A. D. (2011). Why would musical training benefit the neural encoding of speech? The OPERA hypothesis. *Frontiers in Psychology*, *2*, 142.

Patel, A. D. (2014). Can nonlinguistic musical training change the way the brain processes speech? The expanded OPERA hypothesis. *Hearing Research*, *308*, 98–108.

Pietschnig, J., Voracek, M., & Formann, A. K. (2010). Mozart effect–Shmozart effect: A meta-analysis. *Intelligence*, *38*(3), 314–323.

Pryse-Phillips, W. (2003). *Companion to clinical neurology*. Oxford, UK: Oxford University Press.

Rauscher, F. H., & Shaw, G. L. (1998). Key components of the Mozart effect. *Perceptual and Motor Skills*, *86*, 835–841.

Rauscher, F. H., Shaw, G. L., & Ky, K. N. (1993). Music and spatial task performance. *Nature*, *365*(6447), 611.

Reuter-Lorenz, P. A. (2002). New visions of the aging mind and brain. *Trends in Cognitive Sciences*, *6*(9), 394–400.

Riby, L. M. (2013). The joys of spring. *Experimental Psychology*, *60*, 71–79.

Sacks, O. (2006). The power of music. *Brain*, *129*, 2528–2532.

Sacks, O. (2007). *Musicophilia: Tales of music and the brain*. New York, NY: First Vintage.

Schmitt, A., & Falkai, P. (2014). Historical aspects of Mozart's mental health and diagnostic insights of ADHD and personality disorders. *European Archives of Psychiatry and Clinical Neuroscience*, *264*(5), 363.

Schulze, K., & Koelsch, S. (2012). Working memory for speech and music. *Annals of the New York Academy of Sciences*, *1252*(1), 229–236.

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in Psychology*, *5*, 772.

Schellenberg, E. G. (2012). Cognitive performance after listening to music: A review of the Mozart effect. In R. MacDonald, G. Kreutz & L. Mitchell (Eds.), *Music, health, and wellbeing* (pp. 324–338). New York, NY: Oxford University Press.

Sami, S., Robertson, E. M., & Miall, R. C. (2014). The time course of task-specific memory consolidation effects in resting state networks. *Journal of Neuroscience*, *34*(11), 3982–3992.

Steele, K. M., Ball, T. N., & Runk, R. (1997). Listening to Mozart does not enhance backwards digit span performance. *Perceptual and Motor Skills*, *84*(3), 1179–1184.

Steele, K. M., Brown, J. D., & Stoecker, J. A. (1999). Failure to confirm the Rauscher and Shaw description of recovery of the Mozart effect. *Perceptual and Motor Skills*, *88*, 843–848.

Strait, D. L., Hornickel, J., & Kraus, N. (2011). Subcortical processing of speech regularities underlies reading and music aptitude in children. *Behavioral and Brain Functions*, *7*(1), 44.

Strauss, E., Sherman, E., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, tests, and commentary* (3rd ed.). New York, NY: Oxford University Press.

Thompson, R. G., Moulin, C. J. A., Hayre, S., & Jones, R. W. (2005). Music enhances category fluency in healthy older adults and Alzheimer's disease patients. *Experimental Aging Research*, *31*(1), 91–99.

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, mood, and the Mozart effect. *Psychological Science*, *12*(3), 248–251.

Tillmann, B., Janata, P., & Bharucha, J. J. (2003). Activation of the inferior frontal cortex in musical priming. *Cognitive Brain Research*, *16*(2), 145–161.

Ullman, M. T. (2001). A neurocognitive perspective on language: The declarative/procedural model. *Nature Reviews Neuroscience*, *2*(10), 717–726.

Verrusio, W., Moscucci, F., Cacciafesta, M., & Gueli, N. (2015). Mozart effect and its clinical applications: A review. *British Journal of Medicine and Medical Research*, *8*(8), 639–650.

Wallace, W. T. (1994). Memory for music: Effect of melody on recall of text. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(6), 1471–1485.

Wechsler, D. (1997). *WAIS-III: Administration and scoring manual*. San Antonio, TX : The Psychological Corporation.

Zhu, W., Zhao, L., Zhang, J., Ding, X., Liu, H., Ni, E., ... Zhou, C. (2008). The influence of Mozart's sonata K. 448 on visual attention: An ERPs study. *Neuroscience Letters*, *434*(1), 35–40.

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PloS One*, *9*(6), e99868.