How is Musical Activity Associated with Cognitive Ability in Later Life?

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Abstract

Research has suggested that individuals who play a musical instrument throughout adulthood have better preserved executive function. However, mixed results have been found for associations between musical activity and visuo-spatial abilities, and less is known about associations with fluid intelligence. We explored differences between older musicians (N = 30) and non-musicians (N = 30) aged 60-93 years old across a range of neuropsychological measures of cognitive function. Musicians performed significantly better than non-musicians on all domains, which remained after adjusting for age, gender, educational history, languages spoken and physical activity. As a cross-sectional comparison, the results should not be overstated; however, they are consistent with findings suggesting learning a musical instrument throughout the life course may be associated with cognitive benefits. Identifying potential lifestyle factors that have cognitive benefits in later life, such as musical experience, is an important step in developing intervention strategies for cognitive ageing.

Keywords: Musical ability, musical experience, cognitive ability, cognitive ageing, old age, later life

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Most everyday tasks rely upon key cognitive abilities and even in healthy ageing, some of these skills decline with age. Decline has been found in domains of memory, processing speed, reasoning and executive function (Deary et al., 2009). Executive function is an umbrella term that encompasses several cognitive abilities such as inhibition, attention, working memory and cognitive flexibility. The domains within executive function are particularly important in planning, tackling unanticipated challenges and staying focused (Diamond, 2013). Given that cognitive abilities are important in facilitating happy, independent experiences in later life, it is important to understand ways in which people can reduce cognitive decline. A common activity taken up in childhood is the learning of a musical instrument, and research has shown that there may be cognitive benefits for those who have chosen to do so (Sarkamo, 2017).

Given the potential relationship between musical activity and cognition in older age, it is important to first consider how it may relate to cognitive abilities across the lifespan. The 'transfer-effect' (Tranter & Koutsaal, 2008) refers to the influence an acquired knowledge or ability in one domain, may have on the problem-solving abilities or knowledge in another domain. There are two prominent theories regarding musical activity and cognitive transfer-effects. The first of which is the domain-specific hypothesis. This hypothesis suggests that the cognitive benefits associated with musical activity are related to domains that are tightly involved in playing an instrument. In support of this, a longitudinal cohort study assessed children before and after 2 years of musical training on their perception of speech in noise. When compared with a second group that received only 1 year of training, results indicated that the ability to perceive speech in noise was significantly greater after 2 years training versus 1 (Slater et al., 2015). Correlational studies also support this; Forgeard and colleagues (2008) found that musical experience was associated with better auditory discrimination and fine motor abilities in children aged around 10 years old who had received 4.5 years of musical training, compared to those who had not received any. However, contrary to prior research, training was not associated with wider educational or spatial-temporal benefits (Rauscher et al., 1993, 2000; Hetland, 2000). Given that musical activity often requires participants to utilise skills such as reading musical notation, which is essentially the translation of visuo-spatial symbols, required to then perform an action (Stewart, 2008), the younger age of this sample may explain the lack of reported associations in relation to spatial skills. Perhaps reading musical notation had not yet become a competent skill (Gromko, 2004). A clearer difference in visuo-spatial ability could therefore potentially be seen in adults with prolonged experience reading musical notation, something that will be examined in the current study. Further benefits have also been found in verbal memory, aspects of working memory, divided attention, visual attention and processing speed in children and young adults who have received musical training over those who have not received any (Ho et al., 2003; George & Coch, 2015; Palleson et al., 2010; Sachs et al., 2017; Roden et al., 2014).

In contrast, the domain-general hypothesis states that learning a musical instrument has far reaching cognitive benefits, including domains that are related to general intelligence. Schellenberg (2006) reported a moderate positive correlation between the duration of music lessons, general IQ and academic ability in 6-11-year olds. A similar but weaker correlation was reported between playing an instrument in childhood and the IQ of undergraduates. Although the effect sizes appear to be only small or moderate, they were larger than any other factor controlled for, such as age, gender, non-musical activities, family income and parents' education.

The literature surrounding the relationship between musical activity and cognitive ability in older adults is developing, but uncertainty remains over which specific cognitive domains are associated with the learning of a musical instrument. Near transfer-effects (beneficial effects on cognitive domains closely related to playing an instrument) have been reported, like those found by Slater and colleagues (2015). A recent study used auditory processing tasks with musicians and non-musicians. Results revealed that in older age, those who had actively taken part in music were better equipped to deal with the auditory demands of everyday life and hearing speech in noise (Parbery-Clark, 2011), an ability known to decline in later life. This has been supported by further evidence suggesting musicians experience less age-related decline in the temporal resolution of the auditory system, the ability to hear speech in noise and throughout central auditory processing (Zendel & Alain, 2012; Benjamin Rich et al., 2012). Arguably, this could be related to the ability to inhibit interfering stimuli, perhaps more closely associated with executive function. However, it is worth highlighting the cross-sectional design of these studies and emphasising the need for more longitudinal training paradigms.

Research into transfer effects of musical activity in older populations has also revealed associations between musical activity and the preservation of executive function. In a study of 19 musicians and 24 non-musicians aged 50-77 years of age, musicians performed better than non-musicians on near-transfer tasks (auditory processing/auditory conflict). Musicians also performed better on visuo-spatial span and aspects of cognitive control. After controlling for educational history, the authors concluded that high-levels of musical expertise were associated with domain-general benefits (Amer, et al., 2013). However, the authors describe visuo-spatial abilities and cognitive control as far transfer. Arguably, both of these abilities are closely related to the performance of an instrument given that musicians must process multiple stimuli and read musical notation. The benefits related to cognitive control have also received support in a test measuring the electrophysiological responses of 17 musicians and 17 non-musicians. Using the Go/No-Go task, experimenters found that musicians committed fewer errors and showed better inhibited prepotent response tendencies, meaning they were better able to inhibit the response that was with the greatest habit strength, and then selectively respond more accurately (Moussard, et al., 2016). The findings could be due to prolonged practice in the skills involved in performing. However, it is worth noting the modest sample sizes within the area.

Hanna-Pladdy and colleagues tested the cognitive abilities of 70 older adults, aged 60-83 years old. They were split into 3 groups, 22 high-activity musicians (>10 years training), 27 low-activity musicians (1-9 years training) and 22 non-musicians. The Trail-Making tasks showed the largest group difference, whereby high-activity musicians performed better than non-musicians. Non-verbal memory, visuo-motor speed and processing, and cognitive flexibility were all significantly better in high-activity musicians, while the low-activity musicians' performance was between that of non-musicians and high-activity musicians, suggesting a linear relationship between prolonged musical practice and cognitive abilities (Hanna-Pladdy et al., 2011). In a follow-up study, 33 musicians and 37 non-musicians were tested on a similar set of cognitive domains replicating the first study, but also reporting significant differences in verbal fluency, verbal memory, visuospatial and planning functions (Hanna-Pladdy & Gajewski, 2012).

Many of the studies have used cross-sectional comparisons, though an intervention study assessed 29 older adults aged 60-83 years old who were split into either a musical group, in which they took part in 4 months of piano lessons, or a control group, who took part in exercise, painting classes and computer lessons. Post-intervention, the musical group performed better in both Trail Making A and B, a task that exploits several areas of executive function, including attention, cognitive flexibility and inhibition, while also testing motor functions and visuomotor scanning. The same effect was also found in the colour-word Stroop test and in tests of manual dexterity (Seinfield et al., 2013). This study suggests multiple cognitive benefits over a relatively short period and is consistent with domains examined in previous literature.

Associations between musical practice and cognitive benefits have also been supported by neuroscientific evidence. Enhancement of cognitive control and working memory was found when measuring blood-oxygenation level dependent (BOLD) in musicians and non-musicians. Better performance in reaction times and lower error rates in memory and attention tasks coincided with greater BOLD responses on the lateral pre-frontal cortex and lateral parietal cortex in musicians (Palleson et al., 2010). A recent study found evidence of more efficient use of neural resources in the frontal lobe regions in musicians when compared to non-musicians. Musicians showed lower activation in the dorsolateral pre-frontal cortex and the superior frontal gyrus when outperforming controls in both spatial and non-spatial working memory tasks (Alain, et al., 2018). Given that the frontal lobes are subject to age-related declines and are associated with executive function, this may account for the better performance in cognitive tasks relying on executive function in musicians. An fMRI study in which expert musicians, amateurs and non-musicians listened to a set of composed string quartets with hierarchical manipulated endings (musical phrases were changed from what would be harmonically expected) found that behavioural responses perfectly separated the groups according to musical expertise. When comparing brain responses, compelling evidence was found for step-wise modulations (changing harmonic key) in the fronto-temporal network, which is thought to host functions of attention and working memory (Oechslin, 2013).

Neuroscientific evidence also notes better preservation of lower level perceptual and motor networks in musicians with greater plasticity from long-term training, involving multi-sensory and motor functional integration (Cheng et al., 2012). This has also been found in auditory processing (Bidelman & Alain, 2015; Fauvel et al., 2014). The modification of functional brain structure has also been related to control and visual processing; the neural mechanism for letter processing differed in musicians and non-musicians, suggesting expertise may modify neural substrates (Proverbio et al., 2013).

The current study focussed on the cognitive domains relating to executive function, and sought to clarify the relationship between musical experience and visuo-spatial abilities, which appear to have produced more mixed results in children and adults, while measures of reasoning were included to assess whether musical expertise could be related to general IQ (Schellenberg, 2006) and thus support the domain general hypothesis. Older adults completed a battery of cognitive tests, to assess spatial abilities, fluid intelligence and executive function. It was predicted that older musicians would outperform non-musicians on tasks involving visuo-spatial abilities. Musicians were also expected to outperform non-musicians in tasks relying on elements of executive function, due to the employment of abilities such as attention, inhibition, working memory and cognitive flexibility during the performance of music.

Methods

Participants

Sixty community-dwelling older adults (53% Female) between 60 and 93 (M=69.66) years of age were recruited. Interviews and testing took place in libraries and community centres across the North East of England and throughout Edinburgh, as well as at Heriot-Watt University. Participants were separated into two groups based on their musical experience. Non-musicians (*n=30*) consisted of those who had never played a musical instrument or had stopped within a year (13 males and 17 females aged 60-93 (M=70.13)). The musician group consisted of 15 females and 15 males aged 60-88 years of age (M=69.20). Most musicians had played their chosen instrument(s) for more than 10 years, however, five had started playing in retirement and had thus been playing for between 5 and 10 years, only one musician was no longer actively participating in the practice of their chosen instrument. All participants were fully independent, healthy older adults who did not report symptoms of psychiatric or neurological disease.

Group Comparisons and Musician Characteristics

As shown in Table 1, the two groups did not significantly differ on their average physical activity per week, number of languages spoken (80% of the sample speaking one language, 18.7% speaking two and 1.7% speaking three or more languages), or educational history.

Thirteen musicians had been trained in more than one genre of music, with the most common combination being Classical and Folk music. In relation to reading musical notation, 80% (N =24) of the musical sample could sight read notation, with the other 20% (N=6) stating that they could read it but were not capable of sight reading. Most of the musician sample was classically trained and only four had been trained in Jazz and two in Rock music. Twenty-five musicians also played multiple instruments. The most common of which was the Piano with twenty participants taking this instrument up; twelve participants played a string instrument (Violin, Viola, Cello, Guitar, Bass Guitar), eleven played a woodwind instrument (Saxophone, Bassoon, Clarinet, Oboe, Flute), and three played a brass instrument (Tuba, Horn, Cornet). Only two participants also played a percussion instrument (Hand Drum, Timpani).

2.2 Procedure

Musical participants were recruited through various musical groups/ensembles and orchestras around the North East of England and Edinburgh. Non-musicians were recruited through distribution of flyers to community groups and community centres/libraries in the same areas.

Prior to testing, participants were given a comprehensive information and consent form, approved by the Heriot-Watt Psychology Ethics Committee. Participants completed a background questionnaire to obtain information on age, gender, educational history, occupational history, physical activity (days per week) and number of languages spoken. Educational history was given in terms of academic achievement (i.e. High-School Graduate, Bachelor's Degree, Masters, etc.) and was then converted into average years in education. Occupational history was characterised as primarily employed full-time for wages, employed part-time for wages, volunteer, military, or unable to work. Physical activity was classified as any form of activity that increased a person's heart-rate for 30 minutes or more, at one time throughout a day.

Participants then completed each of the neuropsychological assessments detailed below, comprising: The Spatial Reasoning Test, the congruent and incongruent Stroop tests, Trail-Making A and B, the Abstract Reasoning Test, the Single Letter Cancellation task, and Digit Span test. Testing took approximately thirty to forty minutes for each participant.

Materials

Spatial Reasoning Test (123test.com): The Spatial Reasoning test is a measure of spatial temporal reasoning skills that requires participants to picture and manipulate objects in three dimensions to draw conclusions from limited information. Participants responded to ten questions and thus, the test was scored out of ten. Similar, standardised versions of this test can be found in several papers (Bodner & Guay, 1997; Prieto & Velasco, 2010; Tapley & Bryden, 1977; Gluck et al., 2007). Someone with good spatial temporal reasoning will be good at mentally moving objects in space to solve multi-step problems. A simple everyday example may be packing boxes into cars.

The Colour-Word Stroop test (A & B): The Stroop test (Stroop, 1935) is a widely used two-part test used as a measurement of executive function, originally developed to measure selective attention and cognitive flexibility. It is widely described as measuring an individual's ability to shift cognitive set from a learned rule, to a novel one (Homack & Riccio, 2004) while inhibiting incongruent information. In the first test (congruent), participants were asked to read aloud a list of colour words as fast as they could, scanning each line from left to right until they reached the bottom of the page. Time taken was the dependent variable. In the second, the colour of the ink that the word is written in, does not match the colour word itself (incongruent). Participants were then asked to read aloud the colour of the ink that the word is in as fast as they could while scanning from left to right until they reached the bottom of the page. The time taken to complete was measured.

Trail-Making Tasks (A&B): The Trail-Making task (Partington & Leiter, 1949) is an extensively used, simple neuropsychological assessment measuring a wide variety of cognitive processes. These include attention, visual search and scanning, sequencing and shifting, psychomotor speed, cognitive flexibility and the ability to execute and modify a plan of action.

Condition A requires participants to draw lines from one circled number to another in a numerical sequence as fast as possible without lifting their pen from the paper until it has been completed. The time taken to complete is measured. Condition B changes the rule and participants were then required to draw lines to circled number and letters, alternating between numerical and alphabetical order (i.e., 1-A-2-B-3-C, etc.) as fast as possible, again without lifting the pen from the paper until the task was completed. Again, the time taken to complete was measured.

Abstract Reasoning Test (123test.com): The Abstract Reasoning test included ten multiple choice questions. Each question consisted of an abstract pattern or sequence with one section missing and replaced by a question mark. Participants had to choose from the four available options which shape belonged in the place of the question mark. The task requires participants to spot the logical rule that underlies the pattern and choose from the options accordingly. This task is a measure of one's non-verbal reasoning ability and lateral thinking skills. As with the Spatial Reasoning test, this was scored out of ten.

Single Letter Cancellation Task (SLCT): The Single Letter Cancellation task is a quick measure of attention/concentration, visuo-spatial scanning abilities and a test of spatial neglect. Participants were asked to scan each line from left to right and draw a line through ever letter 'H' that they could see. This was done until they reached the bottom of the page, as rapidly as possible. Time taken to complete the task was measured.

Digit Span (Forwards & Backwards): Digit span is a measure of working memory capabilities. More specifically, it is a measure of verbal working memory capacity. Participants were read a sequence of digits, beginning with two and rising to nine digits in length. They were then required to repeat the digits back in the same order. There are eight rounds of two trials for each number of digits read out (i.e Round 2-Trial 1: 4-9-5, Trial 2: 3-8-6). If a participant got both sequences wrong in a single round, then the test was stopped, and their total score was added up. The backwards digit span has the same structure but only goes up to eight digits. In this task a sequence was read aloud, and the participant was required to recall it in reverse order.

Again, if a participant got both trials wrong then the test was stopped, and their score was added up. The final score was the sum of both the forwards and backwards digit span.

Statistical Analyses

Most of the data satisfied the assumptions needed for parametric testing (normality data in Supplementary Table 1). However, both Stroop A and Trails B were positively skewed; a log transformation successfully transformed Trails B, while a reciprocal (inverse) transformation was required for Stroop A (Supplementary Table 1). The transformed Stroop A and Trails B were used for all analyses.

Between-group t-tests were conducted on the demographic and neuropsychological measures to determine differences based on musical activity (musicians vs non-musicians). Following this, analyses of covariance (ANCOVA) were conducted in which possible confounding factors such as age, gender, educational history, number of languages spoken, and physical activity were included (all are associated with cognitive ability or ageing). As 90% of participants described their occupational history as ‘Employed full-time for wages’, occupational status was not included in the analyses.

Results

In addition to the demographic group comparisons detailed above, Table 1 also displays that for all neuropsychological measures except the congruent Stroop test, there was a significant between-group difference: musicians performed better than non-musicians.

Correlations

Pearson’s correlations were conducted; as expected, all cognitive tasks were correlated, for example moderate positive correlations were found between performance on Spatial Reasoning and Abstract Reasoning (*r=.595),* Trails A and Stroop B (*r=.693),* and Trails B and Stroop B (*r=.633*). Age had a small positive correlation with Stroop B time taken (*r=.325*) and a moderate positive correlation with Trails A time taken (*r=.439*); older participants performed more poorly than younger participants. There was also a moderate positive correlation between years playing for musicians and Digit Span score (*r=.449).* The full correlation table is presented in Table 2.

Analyses of Covariance (ANCOVA)

Analyses of covariance (ANCOVA) were conducted to test the main and interaction effects of the between-subjects group factor (musicians vs. non-musicians) for each of the neuropsychological measures while controlling for the covariates. Checks were carried out to confirm homogeneity of regression and linear relationship between the covariates and dependent variable. The resulting p-values were then adjusted for multiple comparisons using the Benjamini-Hochberg method and the False Discovery Rate (FDR) was set at .05. See Table 2 for *f* figures and raw significance values.

Spatial Reasoning: The ANCOVA for spatial reasoning revealed that when controlling for all the covariates, the between-group difference was statistically significant [*F (1, 52) =11.44, p=.001, partial* n^2*=.180],* with musicians performing better than non-musicians; the adjusted mean score for musicians was 7.39 and for non-musicians was 6.01. Age, educational history, number of languages spoken, physical activity and gender were not significantly related to spatial reasoning performance. The Benjamini-Hochberg procedure was then conducted with an FDR of .05; the p-value for the between-group difference in Spatial Reasoning remained significant.

Stroop A (Congruent): Using the transformed data, the ANCOVA revealed that gender was the only covariate significantly associated with Stroop A performance [*F (1, 52) =5.88, p=.019, partial* n^2*=.100].* A t-test revealed that females completed the task more quickly than males (*p=.026).* After controlling for all covariates, there was no significant between-group difference for Stroop A [*F (1, 52) =2.13, p=.150, partial* n^2*=.039*]. The adjusted mean time taken to complete the task for musicians was 44.12 seconds and for non-musicians was 46.94

seconds. The Benjamini-Hochberg procedure revealed that the association with gender did not remain significant once adjusted for multiple comparisons.

Stroop B (In-Congruent): Adjusting for all covariates resulted in a statistically significant between-group difference for Stroop B [$F\ (1, 52) = 16.79, p = .001$, partial $n^2 = .244$] whereby musicians performed better than non-musicians; the adjusted mean time taken to complete Stroop B for musicians was 121.31 seconds, with the non-musicians mean 156.23 seconds. Number of languages spoken was also significantly related to Stroop B performance [$F\ (1, 52) = 4.81, p = .033$, partial $n^2 = .05$]. Finally, age was a significant covariate [$F\ (1, 52) = 8.27, p = .006$, partial $n^2 = .137$]. Once the p-values were adjusted for multiple comparisons, the Benjamini-Hochberg procedure with the FDR set at .05 revealed that the between group difference remained significant, as did the covariate age.

Trail-Making A: Adjusting for all the covariates resulted in a statistically significant between-group difference [$F\ (1, 52) = 6.23, p = .016$, partial $n^2 = .105$] with musicians performing better than non-musicians; the adjusted mean times taken were 30.68 seconds for musicians and 35.96 seconds for non-musicians. The ANCOVA also revealed that age was significantly related to Trails A performance, with the largest effect [$F\ (1,52) = 10.64, p = 002$, partial $n^2 = .167$]. Once adjusted for multiple comparisons using the Benjamini-Hochberg test with the FDR set at .05, both p-values for age and Trails A between group difference remained significant.

Trail-Making B: Using the transformed Trails B data, the ANCOVA revealed a significant between-group difference [$F\ (1, 52) = 4.94, p = .031$, partial $n^2 = .085$] with musicians performing better than non-musicians, though this effect was only moderate; the adjusted mean time taken was 62.04 seconds for musicians and 75.86 seconds for non-musicians. Educational history was also significantly related to Trails B performance [$F(1, 52) = 4.97$, *p=.030, partial n²=.086*] The Benjamini-Hochberg procedure with the FDR set at .05 revealed that the p-value for the Trails B between-group difference was no longer significant.

Abstract Reasoning: The ANCOVA for abstract reasoning revealed that after controlling for all covariates, the between-group difference was statistically significant [*F (1, 52) =13.14, p=.001, partial n²=.244*]. Again, musicians outperformed non-musicians in this task with adjusted mean scores of 7.38 and 6.09 out of 10 respectively. The Benjamini-Hochberg method with the FDR set at .05 revealed that the between-group Abstract Reasoning difference remained significant after being adjusted for multiple comparisons.

Single Letter Cancellation Task: After adjusting for the covariates, the ANCOVA revealed that the between-group difference was statistically significant [*F (1, 52) =7.66, p=.008, partial n²=.126*], in that musicians performed better than non-musicians. The adjusted mean time taken to complete the task was 92.88 seconds for musicians and 105.05 seconds for non-musicians. Physical activity was shown to have the largest effect on SLCT performance [*F (1, 52) =12.83, p=.001, partial n²=.195*] with those who took part in more physical activity performing better. The Benjamini-Hochberg procedure with the FDR set at .05 revealed that both p-values for the Single Letter Cancellation between-group difference and physical activity remained significant once adjusted for multiple comparisons.

Digit Span: The ANCOVA for digit span revealed that after controlling for all covariates, the between-group difference was statistically significant with a large effect size [*F (1, 52) =11.49, p=.001, partial n²*=.178] in which musicians performed better than non-musicians. The adjusted mean sum of both the forwards and backwards digit span was 21.74 for musicians and 17.96 for non-musicians. No other covariate was significantly associated with task performance. The Benjamini-Hochberg procedure with the FDR set at .05 revealed that the between-group Digit Span difference remained significant after adjusting for multiple comparisons.

Discussion

The results of the current study support the hypothesis that healthy older adults who played a musical instrument would outperform older non-musicians on several cognitive tasks representing the domains of executive function, visuo-spatial abilities and fluid intelligence. When controlling for covariates including age, gender, educational history, number of languages spoken and number of days of physical activity per week, the main-effect of group remained statistically significant. After adjusting the p-values to account for multiple comparisons, only the Trail-Making Task B between-group difference was no longer significant. Overall, these results support the domain-general hypothesis for the far-transfer effects of learning a musical instrument (Schellenberg, 2006) as musicians performed better than non-musicians on tasks representing cognitive domains that are not directly related to the learning of a musical instrument. The findings are also consistent with recent literature using similar neuropsychological measures that have reported better visuo-spatial abilities and executive function in older musicians (Amer et al., 2013; Moussard et al., 2016; Seinfeld, 2013; Hanna-Pladdy et al., 2011; Hanna-Pladdy & Gajewski., 2012).

The study supports the suggestion that there are visuo-spatial benefits in older musicians, a domain that has provided mixed results. However, the results are novel in that they suggest that there might be differences in the fluid abilities of musicians and non-musicians in older age. The cognitive domains tested within the study are all important predictors of remaining independent and leading a fulfilled later life. Visuo-spatial abilities are a particularly important skill in driving due to the need to estimate the accurate distance between two or more objects. As mentioned, executive functions are crucial in planning, tackling novel problems and in staying focused (Diamond, 2013). Finally, fluid intelligence is required to reason and solve problems. Therefore, a clear understanding of lifestyle factors that might be associated with retained cognitive abilities in later life is crucially important for an ageing population.

Visuo-Spatial Abilities

Musicians often sight-read music while performing and this is something that requires both accuracy and speed. In essence, they must rapidly translate visuo-spatial symbols and perform the required action (Stewart, 2008). As a result, musicians were expected to out-perform non-musicians in the tasks related to spatial abilities (Spatial reasoning, SLCT and elements of Trail-Making) due to increased practice of using this skill in scanning and then visualising notes as individual pieces of a harmonic puzzle. Visuo-spatial ability differences between musicians and non-musicians have not been consistently reported in the literature though the current study's findings are supported by recent research (Hanna-Pladdy & Gajewski., 2012; Amer et al., 2013). As stated, the mixed results within adult and children populations in previous studies could be due to variation within the samples in terms of those who do or do not have sight-reading as a competent skill. Practice in this area has been shown to be associated with visuo-spatial abilities (Lee, 2012) and has also been linked to alterations in brain plasticity (Hyde, 2009). The volume of grey matter in Broca's area has been shown to decrease in older age, but not in those that played a musical instrument (Sluming et al., 2002).

It has since been argued that in sight-reading music, visuo-spatial cognition is related to language decoding and that Broca's area may be involved in controlling this specific inter-relationship in musicians (Jancke, 2009). As a result, Broca's area has been highlighted as a neural substrate that could underpin the ability to sight-read music. In an fMRI study, along with the visuo-spatial network, Broca's area showed activation in musicians but not in non-musicians while performing a similar 3-D mental rotation task to the Spatial Reasoning test employed in this study (Sluming et al., 2007). This would suggest that Broca's area perhaps promotes visuo-spatial performance in musicians but not in non-musicians. The differences in performance on the Spatial Reasoning test between the two groups seen in the current study could be explained by these findings. More research into the exact neural substrates involved will add clarity, as well as testing adults with differing levels of ability in reading musical notation.

Regarding visuo-spatial scanning, processing and spatial neglect, as tested by the Single Letter Cancellation task and Trail-Making tasks, physical activity had the largest association with task performance. This is consistent with research on visual processing speed and scanning (Shatil, 2013; Pesonen et al., 2017). Particularly, when it comes to older adults, mobility appears to be related to performance in these areas (Owsley & McGwin, 2004). However, there was still a significant main effect of group in which musicians performed better than non-musicians when controlling for the covariates. This could also be linked to reading music. When sight-reading, musicians pick out important bits of information while scanning along a line, keeping time with the appropriate tempo of the piece of music being played. Skilled sight-readers have been shown to look further ahead in a musical score than less skilled readers (Goolsby, 1994). This could explain the better performance of musicians in the Single Letter Cancellation task as they may scan further ahead. Gender differences have also been proposed in these areas for younger adults (Vecchia & Girellib, 1998). However, there is no evidence of this being the case in older adults (Zancada-Menendez et al., 2016), and gender differences were not robustly reported in the current study.

Fluid Intelligence

There is a relative paucity of research regarding the learning of a musical instrument and the association with fluid intelligence in older age. Therefore, these results are novel in showing significantly better performance on the Abstract Reasoning test in older musicians. However, the findings should not be overstated as the task itself is only one aspect of a fuller cognitive assessment. The current study has highlighted that more attention in this domain is warranted. Associations between learning a musical instrument and fluid intelligence have been reported in children, but it was concluded that this relationship was mediated by the positive effect musical activity had on executive function (Dege et al., 2011). Other studies reported no evidence for this mediated relationship and it was assumed that children with a higher IQ were just more likely to take up an instrument (Schellenberg, 2011). Very few studies have examined this relationship in older adults. Nevertheless, some have suggested the hippocampus may play a role. Significant positive correlations have been found between the volume of the hippocampus and fluid intelligence in older participants but not young (Reuben et al., 2011). Similarly, hippocampal volume was seen to be greater in musicians than in non-musicians and this predicted fluid intelligence ability (Oechslin et al., 2013). These findings could explain the difference seen between children and adults and supports the results seen in the current study. Again, this finding is likely to do with sight-reading ability in that musicians are reading logical patterns of harmony from a scoresheet. When writing music, musicians must also reason logically due to the rules of harmony and melody and continued practice in this area could in part, explain the current findings. This ability has been associated with increased volume in areas of the medial temporal lobe thought to be associated with fluid intelligence (Gartner et al., 2013). More research is required to examine the differences in fluid intelligence between older musicians and non-musicians on a larger battery to more specifically explore evidence for far reaching transfer-effects.

Executive Function

In contrast to fluid intelligence, the literature exploring associations between learning a musical instrument and executive function is broad. The findings in the current study add to this and are consistent with recent research indicating better performance in tasks relying on inhibition, attention, cognitive flexibility and working-memory (Bugos et al., 2007; Hanna-Pladdy et al., 2011; Hanna-Pladdy & Gajewski, 2012; Amer et al., 2013; Seinfeld et al., 2013; Moussard et al., 2016; Mansens et al., 2017). Equally, neuroscientific evidence suggesting alterations in brain structure relating to these abilities also support the current findings (Palleson et al., 2010; Trainor et al., 2009; Oechslin et al., 2013). The number of languages spoken was also significantly related to Stroop B performance in this study, which is consistent with the literature relating multilingualism and executive function (Wang et al., 2014; Heidlemayr et al., 2014). However, very few people in this sample spoke more than one language and so the effect on performance should not be overstated.

Something that has not been discussed in the recent literature however, is the validity of the Trail-Making task as a measure of difference in elements of executive function between musicians and non-musicians. The relationship between letters and numbers in musicians who have a full understanding of harmony could be more closely linked than in non-musicians. The A-major scale refers to the note A, as the first and B as the second, etc. until it reaches the seventh, which is G. Given that this task required participants to alternate between numbers and letters as fast as possible in consecutive order, envisioning this scale may just be a task specific advantage for musicians and is a tactic that several musicians admitted to using in the current study. Perhaps a different measure of cognitive flexibility, attention, sequencing and shifting would be more suited to testing the difference between musicians and non-musicians. Nevertheless, despite the apparent enhanced performance on this task by musicians, adjusting the result for multiple comparisons revealed that it no longer remained significant. This contrasts previous research relating to this specific task (Seinfeld et al., 2013) and contradicts our prediction. Given the overlap of cognitive domains measured by Trails B, the Stroop test and the SLCT, the fact that the association between musical activity and performance on this task did not remain significant is surprising and requires consistent replication to more fully understand the association. However, the current evidence alongside previous research regarding musical activity and the benefits for executive function in older age is very strong.

There is, of course, the possibility that these results reflect the tendency of those with better visuo-spatial, executive function and fluid intelligence abilities to begin playing an instrument in the first place, or to at least continue playing throughout adulthood. However, evidence supporting this alternative relationship is mixed. A recent study found that in children, those with better cognitive abilities were more likely to take up an instrument and that in adults, higher general IQ positively predicted the duration of time playing an instrument. Nevertheless, the largest predictor of who began music lessons in the first place was personality, specifically openness-to-experience. Therefore, studies exploring links between musical activity and cognitive ability would benefit from additionally considering personality (Corigall et al., 2013). Another developmental longitudinal study examining children and young adults found better performance in reasoning tasks, processing speed and working memory related to duration of time playing an instrument, suggesting a cognitively beneficial relationship between musical activity and cognitive ability (Nutley et al., 2014). Nonetheless, the current findings and present body of literature cannot rule out the possibility of the tendency of those with already better cognitive abilities to take up an instrument, and to continue playing throughout adulthood. As this is the case, further longitudinal and interventional paradigms need to be used in order to clarify the nature of this relationship, both in children and throughout adulthood.

Limitations

There are some limitations within the study. The Spatial Reasoning test and Abstract Reasoning test from 123test.com were selected for consistency with previous studies within practical constraints. The Digit Span task used in this study collated both forward and backwards performance as one score, limiting the analysis to overall performance rather than seprably. To gain a more comprehensive grasp of the underlying mechanisms associated with musical activity, it would be beneficial have forward and backward scores available individually to allow for a more thorough within-group comparison. Future research might consider fuller batteries to allow multiple markers of each given domain, or further domains of interest. While participant recruitment was similarly restricted, the sample size is consistent with much of the extant literature. Importantly, the relatively short assessment with each participant and the cross-sectional design mean that a thorough examination of each domain was not possible and so the results should not be overstated.

Conclusions

The current study highlighted that learning and playing a musical instrument may be associated with cognitive differences in older age and supports musical activity as a potentially cognitively-protective lifestyle factor. Musicians performed significantly better than non-musicians on tasks relating to visuo-spatial abilities, fluid intelligence and executive function. These findings are consistent with previous research regarding the influence of musical activity on the ageing brain and support the domain-general hypothesis for far reaching transfer effects (Schellenberg, 2006). The current findings on the relationship between musical activity and visuo-spatial abilities are suggested as being derived from the skill of sight-reading music. Nevertheless, results should not be overstated as testing with each participant was brief. Future research should focus on a broader assessment of specific domains such as fluid intelligence and visuo-spatial abilities and consider changes across time including the years leading into and throughout retirement. A more in-depth examination of the differences throughout the musician group should also be considered. To achieve this, a wider range of instruments, including voice, should be thoroughly studied to specifically examine what type of musical activity is associated with what cognitive differences (and preferably over time). Similarly, the number of hours per day practiced and what type of practice that may be (whether it be in an ensemble or individual) should become a focal point for future research in order to more clearly uncover the relationship between musical activity and cognitive ageing. While supported as potentially cognitively beneficial, playing an instrument does not often appear to extend into adulthood; one survey reported that only 34% of adults were currently learning to, or practicing playing an instrument (East, 2014). The growing literature surrounding the benefits of musical experience may provide additional incentives for participating in these activities across the life course.

Table 1: *Demographic characteristics and scaled scores for neuropsychological measures*

	Musicians (n=30)	*Non-Musicians (n=30)*	*t*	*Sig. (p<.05)*	*Effect Size*
Age	69.20 (6.61)	70.13 (8.31)	-0.464	.296	0.123
Gender	15 Males 15 Females	13 Males 17 Females	-	.605 (chi-squared)	0.100
Educational History (years)	15.90 (1.90)	15.73 (1.46)	.381	.705	0.100
Physical Activity (days/week)	4.63 (1.88)	4.23(2.39)	0.720	.236	0.186
Languages Spoken	1.27 (0.45)	1.17 (0.46)	0.850	.180	0.219
Occupational History	25 - Full-time 1 - Part-time 4 - Self-Employed	29 - Full-time 1 - Self-Employed	-	.213 (chi-squared)	0.059
Spatial Reasoning	7.43 (1.41)	5.97 (1.99)	3.361	.001*	0.846
Stroop A	44.23 (8.82)	46.83 (8.09)	-1.177	.244	0.307
Stroop B	119.67 (24.31)	157.93 (42.71)	-4.247	.001*	1.101
Trails A	30.40 (6.48)	36.23 (10.77)	-2.543	.014*	0.655
Trails B	61.57 (19.72)	74.66 (30.55)	-1.962	.027*	0.509
Abstract Reasoning	7.40 (1.22)	6.07 (1.20)	4.262	.001*	1.099
SLCT	92.37 (13.59)	105.57 (23.15)	-2.693	.009*	0.695
Digit Span	21.77 (3.91)	17.93 (4.35)	3.588	.001*	0.928

Note: *SLCT = Single Letter Cancellation Task; Full-time = full time employment for wages; Part-time = part time employment for wages. Abstract Reasoning and Spatial Reasoning tests both scored out of 10; Digit Span is the sum of both forwards and backwards scores; Physical Activity is mean days per week.*

Table 2: Associations between demographic and cognitive measures

	Age	Education	Languages	Phys Activity	SLCT	Spatial Reasoning	Stroop A	Stroop B	Abstract Reasoning	Trails A	Trails B	Digit Span
Age	-											
Education	-.328*	-										
Languages	.247	.097	-									
Physical Activity	-.134	.272*	.128	-								
SLCT	.230	-.266	-.001	-.463***	-							
Spatial Reasoning	-.231	.295*	-.130	.246	-.277*	-						
Stroop A	-.165	.136	.050	.105	-.508***	-.010	-					
Stroop B	.325*	-.212	-.225	-.065	.410**	-.267*	-.487***	-				
Abstract Reasoning	-.137	.235	.094	.287*	-.390**	.595***	.308*	-.459***	-			
Trails A	.439***	-.288*	-.049	-.032	.422**	-.290*	-.404**	.693***	-.451***	-		
Trails B	.356**	-.373**	.070	-.181	.486***	-.305*	-.368*	.633***	-.391**	.639***	-	
Digit Span	-.089	.161	.057	-.002	-.340**	.153	.383**	-.531***	.243	-.425**	-.539***	-
Years Playing	.182	.011	.092	-.121	.068	-.251	.001	-.181	.176	-.162	-.200	*.446

Note: *SLCT = Single Letter Cancellation Task. Number of years playing an instrument associations for musicians only (N = 30). Correlations for Stroop A and Trails B are those using the transformed data.*

**p<.05, **p<.01 level, ***p<.001.*

Table 3: *ANCOVA results for musical activity associations with neuropsychological performance*

	Spatial Reasoning	*Stroop A*	*Stroop B*	*Trails A*	*Trails B*	*Abstract Reasoning*	*Digit Span*	*Single Letter Cancellation Task*
Group (M/NM)	*11.44 (.001)*	*2.13 (.150)*	*16.79 (.001)*	*6.23 (.016)*	*4.94 (.031)*	*13.14 (.001)*	*11.49 (.001)*	*7.66 (.008)*
Age	*0.28 (.599)*	*0.84 (.363)*	*8.26 (.006)*	*10.64 (.002)*	*2.79 (.100)*	*0.07 (.790)*	*0.05 (.829)*	*0.85 (.361)*
Gender	*3.11 (.083)*	*5.88 (.019)*	*0.39 (.536)*	*0.38 (.539)*	*0.80 (.375)*	*1.37 (.247)*	*0.07 (.786)*	*3.13 (.083)*
Educational History	*2.87 (.096)*	*0.42 (.518)*	*0.35 (.554)*	*1.68 (.201)*	*4.97 (.030)*	*2.58 (.215)*	*1.23 (.272)*	*0.48 (.491)*
Languages Spoken	*1.77 (.189)*	*0.01 (.991)*	*4.81 (.033)*	*0.74 (.392)*	*0.60 (.442)*	*0.01 (.927)*	*0.02 (.881)*	*0.61 (.420)*
Physical Activity	*1.99 (.164)*	*0.14 (.707)*	*0.43 (.515)*	*0.81 (.371)*	*0.26 (.612)*	*2.88 (.096)*	*0.48 (.490)*	*12.83 (.001)*

Note: The listed covariates were included in all ANCOVA: age, gender, educational history, languages spoken and physical activity. The df for all tests were 1, 52. Figures displayed here are the f statistic (p-value). M/NM=Musicians/Non-musicians. The values given for Stroop A and Trails B are those using the transformed data.

Supplementary Table 1: *Normality data for cognitive measures*

Variable	*Group*	*Skewness (z-value)*	*Kurtosis (z-value)*	*Shapiro-Wilk (p-value)*
Spatial Reasoning	Musicians	-1.05	0.04	.064
	Non-Musicians	-0.56	-0.76	.221
Stroop A	Musicians	3.66	2.89	**.001**
	Non-Musicians	0.76	-0.28	.751
Stroop A (post transformation)	Musicians	-1.81	-0.04	.056
	Non-Musicians	1.10	-0.06	.594
Stroop B	Musicians	0.19	0.07	.477
	Non-Musicians	0.93	-0.98	.111
Trails A	Musicians	1.33	-0.07	.419
	Non-Musicians	1.81	0.58	.192
Trails B	Musicians	2.19	1.13	**.028**
	Non-Musicians	2.59	0.92	**.010**
Trails B	Musicians	0.47	-0.55	.424
(post transformation)	Non-Musicians	0.60	0.00	.743
Abstract Reasoning	Musicians	-0.27	-0.36	.093
	Non-Musicians	0.28	-0.69	.068
Digit Span	Musicians	-1.92	1.78	.242
	Non-Musicians	1.01	0.47	.773

Single Letter Cancellation Task	Musicians	1.18	-0.51	.278
	Non-Musicians	-0.01	-0.28	.844

Note: *Stroop A (post transformation) is the congruent Stroop test after conducting a reciprocal transformation; Trails B (post transformation) is after a log transformation.*

6. References

Alain, C., Khatamian, Y., He, Y., Lee, Y., Moreno, S., Leung, A. W. S., & Bialystok, E. (2018). Different Neural Activities Support Auditory Processing Working Memory in Musicians and Bilinguals. *Annals of The New York Academy of Sciences*.

Amer, T., Kalender, B., Hasher, L., Trehub, S. E., & Wong, Y. (2013). Do Older Professional Musicians Have Cognitive Advantages? *PLoS*.

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. *Journal of Neuroscience*, 1240-1249.

Bodner, G. M., & Guay, R. B. (1997). The Purdue Visualization of Rotations Test. *The Chemical Educator*, 1-17.

Bugos, J., Perlstein, W. M., McCrae, C. S., Brophy, T. S., & Bedenbaugh, P. H. (2007). Individualized Piano Instruction Enhances Executive Fuctioning and Working Memory in Older Adults. *Aging & Mental Health*, 464-471.

Cheng, L., Zhei-wei, G., Yong-xiu, L., Wei, L., Liu, Q., Kendrick, K. M., . . . Li, H. (2012). Musical Training Induces Functional Plasticity in Perceptual and Motor Networks: Insights from Resting-State fMRI. *PLoS*.

Dege, F., Kubicek, C., & Schwarzer, G. (2011). Music Lessons and Intelligence: A Relation Mediated by Executive Functions. *Music Perception: An Interdisciplinary Journal*, 195-201.

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, 135-168.

Deary, I. J., Corley, J., Gow, A. J., Harris, S. E., Houlihan, L. M., Marioni, R. E., . . . Starr, J. M. (2009). Age-Associated Cognitive Decline. *British Medical Bulletin*, 135-152.

East, L. (2014). *Making Music: Teaching, Learning and Playing in the UK.* U.K.: ABRSM.

Fauvel, B., Groussard, M., Chetelat, G., Fouquet, M., Landeau, B., Eustache, F., . . . Piatel, H. (2014). Morphological brain plasticity induced by musical expertise is accompanied by modulation of functional connectivity at rest. *Neuroimage*, 179-188.

Forgeard, M., Winner, E., Norton, A., & Schlaug, G. (2008). Practicing a Musical Instrument in Childhood is Associated with Enhanced Verbal Ability and Non-Verbal Ability. *PLoS*.

Gartner, H., Minnerop, M., Pieperhoff, P., Schleicher, A., Zilles, K., Altenmuller, E., & Amunts, K. (2013). Brain Morphometry shows effects of long-term musical practice in middle-aged keyboard players. *Frontiers in Psychology*.

George, E. M., & Coch, D. (2011). Music training and working memory: An ERP study. *Neuropsychologia*, 1083-1094.

Gluck, J., Dunser, A., Steinbugl, K., & Kaufman, H. (2007). Warning: Subtle Aspects of Strategy Assessment May Affect Correlations Among Spatial Tests. *Perceptual & Motor Skills*, 123-140.

Goolsby, T. (1994). Profiles of Processing: Eye Movements During Sight-Reading. *Music Percept*, 97-123.

Gromko, J. E. (2004). Predictors of Music Sight-Reading Ability in High School Wind Players. *Journal of Research in Music Education*, 6-15.

Hanna-Pladdy, B., & Gajewski, B. (2012). Recent and Past Musical Activity Predicts Cognitive Aging Variability: Direct Comparison with General Lifestyle Activities. *frontiers in Human Neuroscience*.

Hanna-Pladdy, B., & Mackay, A. (2011). The relation between instrumental musical activity and cognitive aging. *Neuropsychology*, 378-386.

Hetland, L. (2000). Learning to Make Music Enhances Spatial Reasoning. *Journal of Aesthetic Education*.

Homack, S., & Riccio, C. A. (2004). A meta-analysis of the sensitivity and specificity of the Stroop Color and Word Test with children . *Archives of Neuropsychology*, 725-743.

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, C. A., & Schlaug, G. (2009). Music Training Shapes Structural Brain Development. *The Journal of Neuroscience*, 3019-3025.

Jancke, L. (2009). Music Drives Brain Plasticity. *F1000 Reports*, 1-78.

Lee, H. Y. (2012). Exploring the Association between Visual Perception Abilities and Reading of Musical Notation. *Perceptual and Motor Skills*, 699-708.

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*, 146-153.

Nutley, S. B., Darki, F., & Klingberg, T. (2014). Music practice is associated with development of working memory during childhood and adolescence. *Frontiers in Human Neuroscience*.

Oechslin, M. S., Ville, D. V., Lazeyras, F., Hauert, C.-A., & James, C. E. (2013). Degree of Musical Expertise Modulates Higher Order Brain Functioning. *Cerebral Cortex*, 2213-2224.

Oechslin, M., Descloux, C., Croquelois, A., Chanal, J., Van De Ville, D., Lazeyras, F., & James, C. E. (2013). Hippocampal Volume Predicts Fluid Intelligence in Musically Trained People. *Hippocampus*, 552-558.

Owsley, C., & McGwin, G. (2004). Association Between Visual Attention and Mobility in Older Adults. *Journal of American Geriatrics Society*.

Palleson, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Kolvisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive Control in Auditory Working Memory Is Enhanced in Musicians. *PLoS*.

Parbery-Clark, A., Strait, D. L., Anderson, S., Hittner, E., & Kraus, N. (2011). Musical Experience and the Aging Auditory System: Implications for Cognitive Abilities and Hearing Speech in Noise. *PLoS*.

Partington, J., & Leiter, D. G. (1949). Patrington's Pathways Test. *Psychological Service Center Journal*.

Pesonen, H., Savic, A. M., Kujala, U. M., & Tarkka, I. M. (2017). Long-term physical activity modifies automatic visual processing. *International Journal of Sport and Exercise Psychology*.

Prieto, G., & Velasco, A. D. (2010). Does spatial visualization ability improve after studying technical drawing? *Quality & Quantity*, 1015-1024.

Proverbio, A. M., Manfredi, M., Zani, A., & Adoni, R. (2013). Musical expertise affects neural bases of letter recognition. *Neuropsychologia*, 538-549.

Rauscher, F. H., & Zupan, M. A. (2000). Classroom keyboard instruction improves kindergarten children’s spatial-temporal performance: A field experiment. *Early Childhood Research Quarterly*, 215-228.

Rauscher, F. H., Shaw, G. L., & Ky, C. N. (1993). Music and Spatial Task Performance. *Nature*.

Reuben, A., Brickman, A. M., Muraskin, J., Steffener, J., & Stern, Y. (2011). Hippocampal Atrophy Relates to Fluid Intelligence Decline in the Elderly. *Journal of the International Neropsychological Society*, 56-61.

Roden, I., Koden, T., Bongard, S., Frankenberg, E., Friedrich, E. K., & Kreutz, G. (2014). Effects of Music Training on Attention, Processing Speed and Cognitive Music Abilities-Findings from a Longitudinal Study. *Applied Cognitive Psychology*, 545-557.

Sachs, M., Kaplan, J., Sarkissian, A. D., & Habibi, A. (2017). Increased engagement of the cognitive control network associated with music training in children during an fMRI Stroop task. *PLoS*.

Sarkamo, T. (2017). Cognitive, Emotional and Neural Benefits of Musical Leisure Activities in Aging and Neurological Rehabilitation: A Critical Review. *Physical & Rehabilitation Medicine*.

Schellenberg, E. G. (2011). Examining the Association Between Music Lessons and Intelligence. *British Journal of Psychology*.

Schellenberg, G. E. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology*, 457-468.

Seinfeld, S., Figueroa, H. E., Eortitz-Gil, J., & Sanchez-Vives, M. V. (2013). Effects of Music Learning and Piano Practice on Cognitive Function, Mood and Quality of Life in Older Adults. *Frontiers in Psychology*.

Shatil, E. (2013). Does combined cognitive training and physical activity training enhance cognitive abilities more than either alone? A four-condition randomized controlled trial among healthy older adults. *Frontiers in Aging Neuroscience*.

Sluming, V., Barrick, T., Howard, M., Cerzayirli, E., Mayes, A., & Roberts, N. (2002). Voxel-Based Morphometry Reveals Increased Gray Matter Density in Broca's Area in Male Symphony Orchestra Musicians. *Neuroimage*, 1613-1622.

Sluming, V., Brooks, J., Howard, M., Downes, J. J., & Roberts, N. (2007). Broca’s Area Supports Enhanced Visuospatial Cognition in Orchestral Musicians. *The Journal of Neuroscience*.

Stewart, L. (2008). Do Musicians Have Different Brains? *Clinical Medicine*, 204-208.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*.

Tapley, M. S., & Bryden, M. P. (1977). An investigation of sex differences in spatial ability: Mental rotation of three-dimensional objects. *Canadian Journal of Psychology*, 122-130.

Trainor, L. J., Shahin, A. J., & Roberts, L. E. (2009). Understanding the Benefits of Musical Training. *Neurosciences and Music III*, 133-142.

Tranter, L. J., & Koutsaal, W. (2008). Age and Flexible Thinking: An Experimental Demonstration of the Beneficial Effects of Increased Cognitively Stimulating Activity on Fluid Intelligence in Healthy Older Adults. *Aging, Neuropsychology & Cognition*, 184-207.

Vecchia, T., & Girellib, L. (1998). Gender differences in visuo-spatial processing: The importance of distinguishing between passive storage and active manipulation. *Acta Psychologica*, 1-16.

Zancada-Menendez, C., Sampedro-Piquero, P., Lopez, L., & McNamara, T. P. (2016). Age and Gender Differences in Spatial Perspective Taking. *Aging Clinical and Experimental Research*, 289-296.

Zendel, B., & Alain, C. (2012). Musicians Experience Less Age-Related Decline in Central Auditory Processing. *Psychology and Aging*, 410-417.