THE EFFECT OF MUSCIAL ACTIVITY ON COGNITIVE FUNCTIONING IN THE DEVELOPING AND AGING BRAIN

BACHELOR-ESSAY BY REINOUD BRENKMAN
SUPERVISED BY EDDY VAN DER ZEE

Faculty of Mathematics and Natural Sciences, University of Groningen (RUG), the Netherlands
12-04-2015

ABSTRACT
Instrumental music training is a very interesting multisensory motor experience. Neuroscientists studied the correlation between behavioral changes and structural brain plasticity in both the developing and aging brain. Research showed that disciplined and structured musical training enhances brain areas like the corpus callosum, the prefrontal cortex and the hippocampus as well as their functional behavioral involvement like memory and decision-making. These skills are not only useful for music making but can be transferred to other cognitive and behavioral operations. These improvements can facilitate brain development in children as well as healthy aging in adults. Besides that, they indicate that musical activity can be a potential treatment for neurological and developmental disorders. This article focuses on both structural and functional brain differences and integrates musical activity in the Scaffolding Theory of Aging and Cognition and the theory of cognitive reserve.

TABLE OF CONTENTS

1. INTRODUCTION:

Interest in lifestyle modifiable factors that have the impact to improve cognitive vitality and delay neurodegenerative diseases is rising. An interesting field of study that has been getting ample attention the last decades is the effect of music on cognition. It is commonly known that listening to music has a great impact on our brain. Multiple areas of the brain, corresponding to reading or solving math problems, show activity to understand elements like rhythm and melody. Recent studies showed that playing an instrument leads to even more activated brain area's that communicate with each other through fast and complex sequences. Practicing the association of motor actions with sound and visual patterns, which is needed to read notes, while receiving auditory feedback affects our brain in several ways (Wan & Schlaug, 2010). If these musical sensorimotor and cognitive abilities can be transferred to nonmusical cognitive abilities, it can be of great value to both the developing as well as the adult brain. The developing brain can be stimulated by musical training, decreasing developmental disorders and making young people more intelligent when they grow older. The aging brain can be kept active enhancing successful aging and decreasing the chance of neurodegenerative diseases like dementia.

This review article summarizes the effects musical training has on the brain and focuses on the implications it may have for child development and healthy aging. It will focus on three different brain area's that might benefit from musical training and its functional meaning; the prefrontal cortex (PFC), the corpus callosum (CC) and the hippocampus. Finally, it will discuss if results found by cognitive and behavioral research can be implemented to the existing scaffolding theory of aging and cognition (STAC) and the cognitive reserve theory, which will be explained subsequently. It answers the question if musical training truly is that favorable, and if so, how it may work in theory and what it can offer to the developing and aging brain. I hypothesized that musical training positively affect brain areas accounting for a healthy development and aging process, and that it supports the STAC model and the theory of cognitive reserve.

2. LITERATURE REVIEW

2.1 EFFECT OF MUSICAL ACTIVITY ON THE DEVELOPING BRAIN

Learning new motor and cognitive abilities is easiest for young people. Their brain is still developing neural circuits. One can say that their brain is not hardwired to act a specific way but can still be easily manipulated to perform new tasks. Training these developing brains in sensorimotor and cognitive abilities can facilitate them in their life span. Research done with adults that had musical training when they were a child shows it can be a prediction of enhanced cognitive performance later in life (Hanna-Pladdy and MacKay, 2011).

Playing a musical instrument combines activity in several brain areas. Table 1 shows a number of brain areas involved in musical activity.

Table 1. Involvement of different brain areas on musical activity

Brain area	Involvement	Reference
Nucleus Accumbens & Amygdala	*Emotional Reaction*	*1*
Prefrontal cortex	*Controls behavior, expression and decision making*	*9, 14*
Motor cortex	*Playing an instrument*	*10*
Corpus callosum	*Connects both hemispheres*	*10*
Auditory cortex	*Perceives and analyses tones*	*10, 19*
Hippocampus	*Memory, experience and context*	*6*
Visual cortex	*Reading music*	*6*

The brain area's this essay focuses on are the corpus callosum, the prefrontal cortex and the hippocampus. These areas are interesting because they are very important in the developing and aging brain, being responsible for i.e. plasticity, behavior and memory. These functions showed a significant increase in activity after musical training.

The CC is the bridge between the two cerebral hemispheres of our brain. It contains numerous axons combined to a bundle of neural fibers facilitating interhemispheric communication. It combines the linguistic and mathematical precision of the left hemisphere with the novel and creative precision of the right hemisphere to perform complex cognitive tasks. Playing a musical instrument is one of these complex tasks in which both hemispheres need to communicate with each other. Understanding musical notation is more or less processed in our left hemisphere, whereas improvising and understanding the rhythm is processed in our right hemisphere. Using MRI scans, Staigeri et. al. (1995) discovered a significant increase in volume of the CC, especially the mid-body portion containing primary sensorimotor and premotor fibers, in musicians compared to non-musicians. As subjects they used professional musicians and age-, sex- and handedness-matched controls. This effect was strongest for those who began their musical training before they were 7 years old. These findings suggest that musical training enhances the size of the CC and that it has a critical maturation period in childhood. Hyde et. al. (2009) also found enhanced activity in the CC. They used children receiving private keyboard instruction as an instrumental group and compared them with children participating in music class in school as a control group. Here the instrumental group also showed significant brain deformation changes, including enhanced CC activity, after 15 months of practice, as shown by MRI scans.

Intensive musical training can also be associated with structural and functional plasticity in the hippocampus, a brain area that is dedicated to learning and memory. A higher density in gray matter is observed in musicians compared to non-musicians. Memories are stored using different tags like an emotional or auditory tag. Retrieving a certain semantic or episodic memory efficiently depends on whether enough of these tags can be triggered to recollect the source (Bjork, 2013). As expected, behavioral observations showed that musicians seem to exhibit enhanced long-term memory functions by creating, storing and retrieving memories more efficiently (Groussard, 2010). Not only long-term memory, but also working memory (WM) can show improvements. This effect is seen both in behavioral and electrophysiological measurements recording event-related-potentials (ERPs). These ERPs measure the brain response as a direct result of a cognitive, sensory or motor event. Musicians perform better in visual and auditory memory tests showing a faster and less effortful update of their WM. This good "working memory update" is the result of a shorter latency and larger amplitude of the third positive potential (P3) in the ERP, and illustrates the effort in which an auditory stimulus can be discriminated (George, 2011). Demonstration box 1 explains the basics of an ERP.

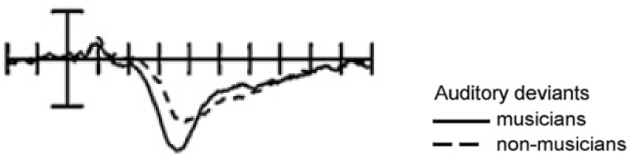
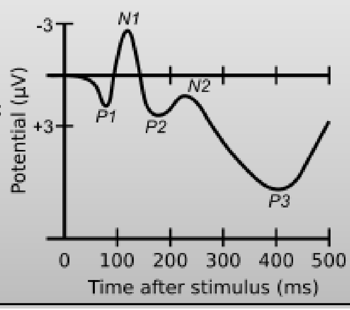


Figure 1. An example of an event-related potential comparing musicians with non-musicians. A short latency and large amplitude of the P3 is seen in musicians. The elevation bar indicates 4μV (George, 2011).

Demonstration box 1

Event-related potentials (ERPs)

ERPs are small changes in electrical brain activity that are induced by a stimulus and recorded by electrodes placed on many sites of the scalp. ERPs are plotted upside down with positive voltage going downward and negative voltage going upward. Many trials are averaged and comparisons are made between groups. Changes in voltage over time are called components and can be positive (P1, P2 or P3) or negative (N1, N2). A component with a large amplitude is associated with a high brain activity level. Having a short latency means it takes less time to evaluate or categorize the event.



The PFC is one of the most flexible structures of our brain. It's the last area to fully mature and the first to show age-related decline. The PFC is an important part of the brain carrying out executive functions like decision-making, personality expression and social behavior. These functions play a critical role in inhibiting the emotional reaction formed by the amygdala. If the PFC is damaged, this top-down modulation is cancelled and can lead to deficits in concentration, problem solving and inappropriate social behavior (Miller & Cohen, 2001).

Hudziak et. al. (2014) found an association between PFC thickness maturation and playing a musical instrument. They state that musical training leads to a more rapid cortical thickness development. Several other studies showed an improvement of functions that are associated with the PFC. One of these studies focused on short-term musical training and its effect on verbal intelligence and executive function. Before and after a music-training program they tested children on their intellectual functioning. They used scores from the Wechsler Preschool and Primary Scale of Intelligence-Third Edition (WPPSI-3). They tested children with spatial attention and memory tasks and found that a musical training program of only 20 days strongly results in improved executive functioning. By this they had also proven that high-level cognitive skill transfer is possible in young children (Moreno, 2011).

Moreno et. al. (2011) not only found an improvement in executive functioning, but also in verbal intelligence. After training, more than 90% of the children in the music-program group performed better on the WPPSI-3 verbal subtest. Just as researchers revealed that CC growth is strongest for musicians that started playing before the age of 7, verbal working memory of musicians with early age of acquisition (less than 9 years of age) is better in these subjects than those with a later age of acquisition (after 9 years of age) (Hanna-Pladdy & Gajewski, 2012). These findings support the theory of a critical maturation period in childhood.

2.2 The aging brain

The basic hardware of cognition significantly declines with advanced age. Many brain areas, including the PFC and the hippocampus, show age-related shrinkage. Both grey and white matter loss in volume starts in the anterior part and gradually affects the posterior part of the brain. Brain plasticity occurs throughout the life span, but declines with age. When an old brain needs to recover from an injury it takes more time and effort. This is seen by a longer duration of cognitive and behavioral deficits.

Normal aging can lead to a small reduction of the CC, but compared to other brain areas the CC stays relatively intact. The aging process differentially affects the functions of the corpus callosum. When older adults are performing a simple reaction task where the corpus callosum is needed for interhemispheric interaction they perform worse than younger adults. But when they perform a task requiring more attentional functions using interhemispheric interaction they outperform young adults (Reuter-Lorenz, 2000). This can be partially explained by the fact that older adults have a 1) slow reaction time and 2) become more bilateral with age. The slow reaction time makes them perform badly in simple reaction tasks (even when the task is bilateral). But when the task is complex, demanding attentional functions, the slow reaction time loses its negative effect and the bilateral predisposition leads to better results. Reuter-Lorenz et. al. discovered this using match trials explained in Figure 2.

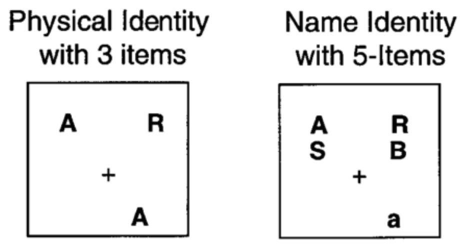


Figure 2. These match trials were used to measure the interhemispheric reaction time in old and young adults. In the (easy) physical identity trial, participants were shown a target letter in the lower row of the display and were asked if the target physically matched one of the probes in the upper row (in this example, A-A). In the (complex) name identity task, based on letter name, the target letter appeared in lowercase and the probes were uppercase (in this example, a-A). Because the target and matched probes appeared in opposite visual fields, hemispheric interaction through the CC was needed in these trials (Reuter-Lorenz, 2000).

The PFC is more extensively affected by white matter loss than by grey matter loss. As explained above, a deterioration of the PFC can lead to deficits in concentration, problem solving and inappropriate social behavior. The latter is due to less activity in inhibitory control, leading to more activity in regions that are supposed to be inhibited like the amygdala. When the PFC is suffering from atrophy, more activation is needed to perform a simple WM task compared to a PFC without atrophy. When the task becomes complex the PFC will also need more activity to correctly retrieve a memory. These findings can be explained by an increase in neural inefficiency (Toepper, 2014).

The grey matter density of the hippocampus declines steeper with increasing age. Losses of 0.3% to 2.1% of volume per year are reported, where men are more vulnerable than women (Ravdin, 2013). This leads to an alteration in hippocampal connectivity and plasticity. There are different areas of the hippocampus where atrophy can lead to different behavioral deficits. For example, a decline in the CA1 region of the hippocampus is particularly associated with Alzheimer's disease and the CA3 region is most vulnerable to stress (Burger, 2010).

A decrease in functioning, affected by atrophy or inefficiency, in these brain areas is closely associated with dementia.

2.3 THE EFFECT OF MUSICAL ACTIVITY ON THE AGING BRAIN

Musical training has shown to be an effective way of improving cognition in children but also to delay degeneration in adults. Several studies investigated the effect of musical training on the aging adult brain.

Research shows that musicians (ages from 60 to 83) with at least 10 years of musical experience scored better in nonverbal memory, naming and executive function tests compared to non-musicians (Hanna-Pladdy, 2011). These cognitive domains are consistent with the areas of cognitive decline in the aging brain (PFC, hippocampus) discussed earlier.

A critical question that needs to be answered is whether people who play an instrument are systematically different to begin with. One way of testing this is using older adults with no musical experience. When musically naïve older adults (ages from 60 to 83) received six months of individualized piano instructions, they performed better on cognitive functions associated with executive function compared to a control group. This effect even consisted after a three-month delay (Bugos, 2007). These results support the theory that musical activity enhances executive function, no musical predisposition is needed to profit from musical activity and that skill transfer is possible even in older adults.

An even better way to test whether people who play an instrument are systematically different is by using a co-twin study. These studies are very interesting because they can control for variables like sex, education level and physical activity but most importantly for preexisting biological differences. One co-twin study discovered that musicians had a 64% lower likelihood of developing dementia or cognitive impairment compared to their nonmusical co-twin (Balbag, 2014). Providing support that musical activity reduces age-related cognitive decline.

2.4 Theories of compensation

2.4.1 Scaffolding Theory of Aging and Cognitive decline

The positive effect of musical activity on the aging brain can be explained by several existing theories on cognitive aging. One of these theories is the STAC model. To maintain homeostatic cognitive function, our brain tries to form scaffolding networks. This theory is proposed in 2009 by Park and Reuter-Lorenz and is called the Scaffolding Theory of Aging and Cognition. It states that the aging brain is forming new strategies to cope with the structural brain changes associated with aging. It is not specific to old age but to the life span as the brain is confronted with cognitive challenges. By strengthening existing connections, generating new connections and disuse of weak connections our brain can find a supplementary, complementary or alternative way to complete complex tasks. These scaffold networks are mostly found in the PFC. Unfortunately these networks cannot compensate enough to erase observable and measureable cognitive decline. Scaffolding networks are less efficient and lead to more errors than the young circuits (Ravdin, 2013; Reuter-Lorenz, 2014)

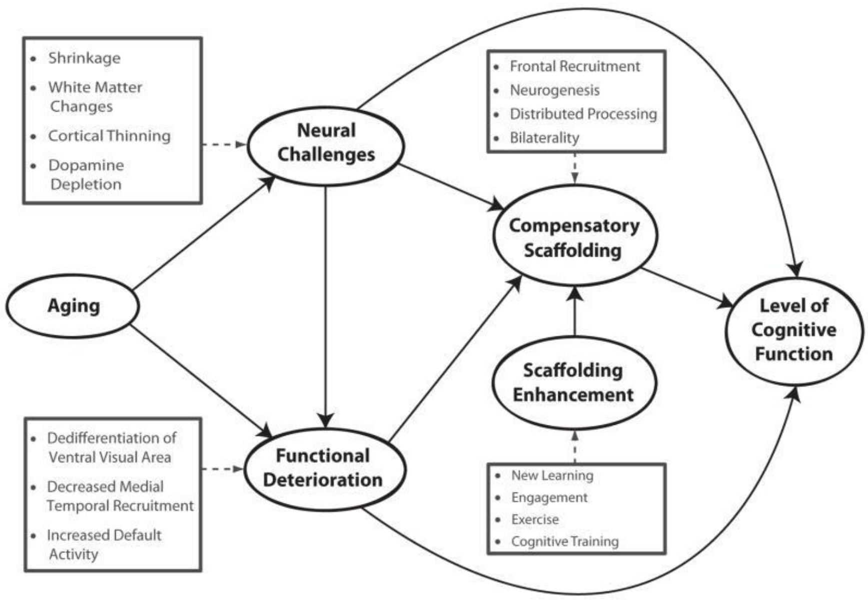


Figure 3: The Scaffolding Theory of Aging and Cognition (Reuter-Lorenz, 2014). This model states that the level of cognitive function is dependent on functional deterioration, neural challenges as well as compensatory scaffolding enhanced by cognitive training (like musical practice).

In 2014 the same researchers came with a revised model named the STAC-r, including life-course variables that impact structure and function of the aging brain. They addressed the affect of experiences in life on compensatory scaffolding (Reuter-Lorenz, 2014). This new model goes in line with the results found in the studies we discussed so far. Musical practice combines new learning, engagement, exercise and cognitive training, all responsible for scaffolding enhancement. The STAC model hypothesizes an improvement in cognitive function and the results from our studies prove it.

2.4.2 Cognitive reserve

Another theory that can explain the positive effect musical activity has on the brain is the theory of cognitive reserve. Much like the STAC model, it refers to the ability to use the neural network of our brain in a more efficient way to compensate brain pathology. By doing this, cognitive reserve diminishes the direct relationship between the degree of brain damage and the clinical manifestation of that damage (Ravdin, 2013). Postmortem studies showed that some elderly women with a healthy cognition did show Alzheimer's plaques at autopsy. Besides that, their brains were significantly heavier than women without these signs of Alzheimer's. Researchers suggested that these women had a cognitive reserve that allowed them to keep their healthy cognition despite their pathology.

Cognitive reserve can be subdivided in two forms: neural reserve and neural compensation. Stern (2013) states that neural reserve refers to the inter-individual variability in the brain networks or cognitive paradigms that underlie the performance of any task in healthy individuals. This can be in the form of differing efficiency, capacity or flexibility in these networks. Neural compensation refers to the use of different brain areas not normally used by individuals with intact brains in order to compensate for brain damage.

Several retrospective studies (studies that examine a participant's life to find a relationship between risk or protective factors and a certain outcome) have found that a number of lifetime exposures can lower the risk for incident dementia. These lifetime exposures include educational and occupational attainment, bilingualism, premorbid IQ and activities in spare time. In theory, these lifetime exposures reduce the risk of Alzheimer's disease by increasing cognitive reserve (Stern, 2013). All of these exposures keep the brain challenged by exposing it to new complex tasks, just like musical activity does. The results of the co-twin study discussed in paragraph 2.3 suggests that musical activity can fit right in, under "activities in spare time", since musicians were 64% less likely to develop dementia.

3. Conclusion

The aim of this essay was to determine how musical activity effects the developing and aging brain and if so, how it can be explained in existing theories. I predicted that it could positively affect brain areas accounting for a healthy development and aging process, and that it supports the STAC model and the theory of cognitive reserve.

Several studies discovered that there is a linear relationship between years of musical participation and cognitive functioning. Thus, increasing evidence support the possibility of a sustained effect of musical practice on cognition. Musical activity stimulates several brain areas combining sensory, cognitive and motor functions. These functions become enhanced with increased practice especially when the age of acquisition is less than 9 years (Hanna-Pladdy, 2012). Musicians seem to have bigger and more efficient brain areas like the corpus callosum, the PFC and the hippocampus. They also perform better on tasks like executive function and working memory, corresponding to these brain areas (Groussard 2010; Hudziak, 2014; Pinho, 2014).

The aging brain declines in volume as a healthy aging process. Especially the PFC and hippocampus lose efficiency, needing more activity to perform a simple task. Studies done with musicians, musically naïve adults, and twins concluded that musical practice significantly improves non-verbal memory, naming and executive function. All of these functions are consistent with areas that show age-related decline. They also show that musicians are less likely to develop dementia or cognitive impairments (Balbag, 2014; Bugos, 2007; Hanna-Pladdy, 2011).

The results found in research that focused on musical activity goes in line with the STAC and cognitive reserve theory. They both explain the difference between healthy and unhealthy aging by the brain's ability to adapt. These adaptations can be set in motion by keeping the brain cognitively challenged. Musical activity is one of these challenges that require repetitive training and seems to enhance brain plasticity.

4. Discussion

The study done by Hudziak et. al. showed that children playing an instrument had a faster maturation of the PFC. But the simple correlation between cortical thickness and years playing an instrument was not proven. This raises the question if cortical maturation is even a positive effect? Does it mean growing up faster? If so, might it reduce plasticity and have therefore a negative effect? The term cortical maturation is not necessarily something positive. A thorough study must be done to further explore the direct association between playing an instrument and PFC thickness.

The question raised by researchers, however, was whether this effect had something to do with musical training or brain activity in general. Hanna-Pladdy did a research in 2012 where they used a control group with the same level of general activity. Musicians had better performance in phonemic fluency, visuospatial judgment, verbal immediate recall and verbal working memory. Level of education best predicted the visuospatial functions. The age of acquisition (<9 years) predicted enhanced working memory. Recent and past musical activity predicted domains associating for verbal and visuospatial abilities. These findings imply that it really is musical activity that improves cognition more than other general activities.

Musical practice might be a possible therapeutic treatment for people with cognitive impairments. Children suffering from attention deficit hyperactivity disorder (ADHD) for example can benefit from these findings. ADHD is a neurological developmental disorder in school-aged children causing problems with executive functions. This is expressed by concentration problems associated with the PFC and can result in poor school performance. If musical practice truly enhances PFC efficiency it can increase the inhibition of unwanted stimuli leading to an increase in focused attention (Seither-Preisler, 2014). Musical therapy could mean a lot to people with agenesis of the CC. The CC of these individuals fails to develop in a healthy manner leading to deficits in non-literal language comprehension, theory of mind and social reasoning (Paul, 2014). Since musical activity stimulates the CC, it could be an effective therapy for these patients.

Taken together, musical activity seems to clearly have a positive effect on both the developing and aging brain. It may not only work as a therapeutic strategy for neurological and developmental disorders, but it seems to enhance the healthy developing brain of children and maintain healthy cognition in older adults. It is my hope that both clinical and educational settings will acknowledge these promising findings and use them to improve their current state.

REFERENCE LIST:

Alluri, V., Toiviainen, P., Jääskeläinen, I. P., Glerean, E., Sams, M., & Brattico, E. (2012). Large-scale brain networks emerge from dynamic processing of musical timbre, key and rhythm. *NeuroImage*, *59*(4), 3677–3689 [1]

Balbag, M. A., Pedersen, N. L., & Gatz, M. (2014). Playing a Musical Instrument as a Protective Factor against Dementia and Cognitive Impairment: A Population-Based Twin Study. *International Journal of Alzheimer's Disease*, *Vol. 2014* [2]

Bjork, R. a., Dunlosky, J., & Kornell, N. (2013). Self-Regulated Learning: Beliefs, Techniques, and Illusions. *Annual Review of Psychology*, *64*: 417-44 [3]

Burger, C. (2010). Region-specific genetic alterations in the aging hippocampus: implications for cognitive aging. *Frontiers in Aging Neuroscience*, *2*(October), 140 [4]

George, E. M., & Coch, D. (2011). Music training and working memory: An ERP study. *Neuropsychologia*, *49*(5), 1083–1094 [5]

Groussard, M., La Joie, R., Rauchs, G., Landeau, B., Chételat, G., Viader, F., … Platel, H. (2010). When music and long-term memory interact: Effects of musical expertise on functional and structural plasticity in the hippocampus. *PLoS ONE*, *5*(10) [6]

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*, *6*(July), 1–11 [7]

Hanna-Pladdy, B., & MacKay, A. (2011). The relation between instrumental musical activity and cognitive aging. *Neuropsychology*, *25*(3), 378–386 [8]

Hudziak, J. J., Albaugh, M. D., Ducharme, S., Karama, S., Spottswood, M., Crehan, E., … Botteron, K. N. (2014). Cortical Thickness Maturation and Duration of Music Training: Health-Promoting Activities Shape Brain Development. *Journal of the American Academy of Child & Adolescent Psychiatry*, *53*(11), 1153–1161.e2 [9]

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). The effects of musical training on structural brain development: A longitudinal study. *Annals of the New York Academy of Sciences*, *1169*, 182–186 [10]

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annu. Rev. Neurosci. 2001*, 24:167–202 [11]

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-Term Music Training Enhances Verbal Intelligence and Executive Function. *Psychological Science*, *22*(2004), 1425–1433 [12]

Paul, L. K., Corsello, C., Kennedy, D. P., & Adolphs, R. (2014). Agenesis of the corpus callosum and autism: A comprehensive comparison. *Brain*, *137*(6), 1813–1829 [13]

Pinho, A. L., de Manzano, O., Fransson, P., Eriksson, H., & Ullén, F. (2014). Connecting to Create: Expertise in Musical Improvisation Is Associated with Increased Functional Connectivity between Premotor and Prefrontal Areas. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *34*(18), 6156–63 [14]

Ravdin, L. D., & Katzen, H. (2013). *Handbook on the Neuropsychology of Aging and Dementia*. *Clinical handbooks in Neuropsychology, New York University* [15]

Reuter-Lorenz, P. A., & Park, D. C. (2014). How Does it STAC Up? Revisiting the Scaffolding Theory of Aging and Cognition. *Neuropsychology Review*, *24*(3), 355–370 [16]

Reuter-Lorenz, P. a, & Stanczak, L. (2000). Differential effects of aging on the functions of the corpus callosum. *Developmental Neuropsychology*, *18*(1), 113–137 [17]

Seither-Preisler, A., Parncutt, R., & Schneider, P. (2014). Size and Synchronization of Auditory Cortex Promotes Musical, Literacy, and Attentional Skills in Children. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *34*(33), 10937–10949 [18]

Skoe, E., & Kraus, N. (2012). A Little Goes a Long Way: How the Adult Brain Is Shaped by Musical Training in Childhood. *Journal of Neuroscience*, *32*(34), 11507–11510 [19]

Staigeri, J. F., & Steinmetz, H. (1995). Increased corpus callosum size in musicians. *Neuropsychologia*, *33*(8), 1047–1055 [20]

Stern, Y. (2014). Cognitive reserve: Implications for assessment and intervention. *Folia Phoniatrica et Logopaedica*, *65*(2), 49–54 [21]

Toepper, M., Gebhardt, H., Bauer, E., Haberkamp, A., Beblo, T., Gallhofer, B., … Sammer, G. (2014). The impact of age on load-related dorsolateral prefrontal cortex activation. *Frontiers in Aging Neuroscience*, *6*(FEB), 1–10 [22]

Wan, C. Y., & Schlaug, G. (2010). Music making as a tool for promoting brain plasticity across the life span, *Neuroscientist, 16*(5), 566–577 [23]