



The Motor and Cognitive Effects Associated with Musical Training: a Narrative Review

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April 4, 2024

THE MOTOR AND COGNITIVE EFFECTS ASSOCIATED WITH MUSICAL TRAINING: A REVIEW OF THE LITERATURE

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Year: 2024

Abstract: Music is an element constantly present in our society, regardless of time or location. Archaeological evidence reveals the possible existence of musical instruments in prehistoric times, showing a long-lasting relationship with music. Currently, studies have grown that indicate that musical practice (musical instrument training and singing) could generate effects that would benefit musicians. Such data gave rise to the hypothesis that musical training could be an interesting stimulus for cognitive and motor development. The aim of this study was to synthesize current evidence (last 10 years) on the influence of musical practice on motor and cognitive developments. A critical narrative review of the literature was carried out. Discuss the effects of musical training exposure in different age groups and the possible implications for neuropsychomotor development and motor rehabilitation.

Keywords: music training, music practice, effects, brain, motor

Introduction

The relationship between music and humanity dates back to prehistory (around 36,000 years), archaeological evidence suggests that homo sapiens sapiens already produced rudimentary bone wind instruments in the Paleolithic period (Zhang, Xiao & Lee, 2004; Killin, 2018). If the long-lasting origin of music dates back to prehistory, its diversity of characteristics is so vast that it lacks a precise consensus regarding its definition (Mithen, 2009).

Considering that its permanence and presence are independent of time and place, its emergence could be linked to the evolution of human communication (Mithen, 2009). Therefore, music is one of the oldest arts and still intensely present in contemporary society.

In addition to entertainment and pleasure, music has been explored as an effective resource to induce specific behaviors. In the commercial sector, companies use music to create a bond with customers, which favors the consumption of goods and/or services. In cinema, music is an indispensable resource to enhance immersion in the narrative and enhance the emotional effects of the plot (Esfidani, Rafiei Samani & Khanlari, 2022; Hoeckner, Wyatt, Decety & Nusbaum, 2011).

The effects of music are linked to its ability to stimulate different brain areas with the same stimulus. In a recent meta-analysis it was found that only by listening to music it is possible to produce activations bilaterally in the frontal, temporal, striatal and cerebellar regions (Chan & Han, 2022). Going beyond passive appreciation, when comparing the brains of music practitioners and non-music practitioners, significant differences in gray matter volume were seen in the motor, auditory and visuospatial regions in favor of the musical group (Gaser & Schlaug, 2003).

Furthermore, the effect of music and its practice is not limited to changes in behavior and brain activation, as this can positively influence motor learning and motor performance. In the study of (Bonassi et al., 2023) it was demonstrated that pleasant melodies can improve motor components involved in learning a specific test sequence, complementing this finding, the study of (Taheri, Razeghi, Choobineh, Kazemi, Rasipisheh, 2022) proved that ambient music accelerates the performance of skills and working memory of students.

Given the context, several studies have proposed to investigate the effects of music on motor and cerebral effects, this interest particularly comes from the possibility of implications in the rehabilitation and cognitive development sector. Therefore, the objective of this review was to synthesize the current evidence on the influence of musical practice on motor and cognitive outcomes.

Method

The articles selected to integrate the general analysis of this review should be published in the 2013-2023 time frame. The choice of articles was made according to their theme. The searches were completed on 12/10/2023, using the PubMed, Scielo and Google Scholar databases. The data was extracted and interpreted by the authors according to their expertise on the subject.

Musical training in children

Exposing children to music has always seemed like a very productive hobby and happens quite frequently, but beyond that, several recent studies have investigated the effects of musical training on children. It is hypothesized that early exposure could improve/facilitate neural processes involved in hearing, motor coordination, brain functions and structures involved in cognition, speed of reasoning and working memory (Loui, Raine, Chaddock-Heyman, Kramer & Hillman, 2019; Martins, Neves, Rodrigues, Vasconcelos & Castro 2018; Carpentier, Moreno, McIntosh, 2016; Gleichmann, Pinner, Garcia, Hakeem, Kodituwakku, Stephen, 2022; Tervaniemi et al., 2021; Bergman Nutley, Darki & Klingberg, 2013)

There were significant results with the musical interventions in this audience. In the study by (Loui, Raine, Chaddock-Heyman, Kramer & Hillman, 2019) it was found that children who had musical practice for at least 30 minutes per week had better verbal and intellectual skills than the group that did not have such experience. Corroborating this data, in the study by (Bergman Nutley, Darki & Klingberg, 2013), it also concluded that the training was associated with an improvement in reasoning, working memory and mathematics.

However, the question arises, when does the child have a condition or pathology? Could musical training be positive too or a fruitless attempt? The study by (Gleichmann, Pinner, Garcia, Hakeem, Kodituwakku, Stephen, 2022) answered this question when it evaluated the neuropsychological effects of musical training in children with fetal alcohol spectrum disorders. Exposure to musical training has been shown to improve neural levels of attention. This is important information to illustrate that musical training is not restricted to a population of asymptomatic children, and that it can be beneficial in conditions that compromise attention levels.

In addition, going beyond cognitive factors in the study (Martins, Neves, Rodrigues, Vasconcelos & Castro 2018), motor skills related to motor coordination were measured in three groups: control,

basketball and music. It was found that dexterity and bimanual motor coordination had a robust superiority in favor of the musical training group compared to the other groups.

What would be the ideal starting age for musical training to produce effects on children's neuropsychomotor development? None of the studies that made up this review set out to answer this question, however it is something considerable when we think about a strategy that, in addition to well-being, can possibly affect their cognitive and motor development (regardless of an asymptomatic state or not). Although specific studies are needed to elucidate this issue, the age range chosen for interventions can give us guidance on this issue.

Ages ranged from 4-25 years (Bergman Nutley, Darki & Klingberg, 2013, Carpentier, Moreno, McIntosh, 2016) (this data is explained by a long-term study that carried out multiple collections over the years), but the most prevalent ages were around 8 years of age (Martins, Neves, Rodrigues, Vasconcelos & Castro 2018; Gleichmann, Pinner, Garcia, Hakeem, Kodituwakku, Stephen, 2022; Tervaniemi et al., 2021). The relevant fact is that everyone obtained positive results regarding the variables analyzed, so that there was no superior effect in one age group. The study by (Bergman Nutley, Darki & Klingberg, 2013) carried out multiple collections over the years, and also found that there was no development window where the results were more expressive.

Consideration needs to be made regarding the type of musical training, intensity and content. Tasks given to children must also consider the child's age and stage of development and their particular evolution with a musical instrument. Although it is an important element for development, the playful and pleasurable context of the experience cannot be removed to the detriment of an exhaustive performance, which can actually reduce the child's adherence and liking to the training. Moderation and fun are the guidelines for musical training with children.

Musical Training in Adults and Elderly

There are some recent studies that have investigated the effects of musical training with the adult population (Wirth et al., 2021; Ullén, Mosing, Madison, 2015; Amengual et al., 2013; Cheung, Chan , Liu, Law, Wong, 2017) . However, the samples were different, two studies used an asymptomatic adult population, one study evaluated the effects of musical training in the elderly (over 60 years old) and another study evaluated the intervention with post-stroke patients.

When evaluating the effects of musical training in asymptomatic adults, we had divergent results. In the study conducted by (Gaser & Schlaug, G, 2003) who carried out a co-hort study with a pair of twins who were exposed to musical training, it was found that musical practice may be associated with a more stable motor performance, however the effect is less significant when external variables are controlled. (environment). On the other hand, in the study by (Cheung, Chan , Liu, Law, Wong, 2017), which compared two groups, one with musical training and the other without musical training, it was found that the group that had the training showed a significant increase in the coherence of the right and left intrahemispheric EEG throughout the theta range during the encoding phase of verbal memory.

In the study by (Wirth et al., 2021), the association between music production throughout life and the maintenance of cognition was evaluated, comparing a group with musical training and another without training. It was found that the musical training group achieved better results in global cognition, working memory and executive function. This work had asymptomatic elderly people in the early stages of cognitive decline and Alzheimer's disease. This study gives us long-term insight into the effects of musical training, which is protective of the maintenance of cognitive functions. And in turn, this data is important as it opens up a range of possibilities for implementing musical training during senescence.

Would musical training be effective when considering a population affected by neurological pathology? According to the study by (Amengual et al., 2013), significant motor gains are also accompanied by neuroplastic changes in patients with chronic stroke after just 20 music sessions. This study found an increase in the excitability of the affected hemisphere after training.

Such studies offer an interesting panorama for motor rehabilitation, patients with neurological pathologies could benefit from strategies based on musical training for recovery and maintenance of function. One of the classic guiding principles of neuroplasticity is that of Use and Disuse and Repetition, so one of the problems in the physiotherapy process is how to make a therapy motivating, even though it requires frequent intensity and a high degree of repetition. Perhaps adhering to a complementary protocol with musical training could provide a great motivator for this challenge.

Frequency for musical training

What is the minimum time to produce beneficial motor and cognitive effects with musical training? The protocol with the minimum time that was covered by this review carried out musical training for 4 weeks and the protocol with the longest duration lasted 2 semesters (Amengual et al., 2013, Tervaniemi et al., 2021). Interestingly, the studies that used a more limited time of approximately one month (Amengual et al., 2013, Carpentier, Moreno, McIntosh, 2016) had a more intense frequency with daily sessions. So there does not seem to be an exact determination of how much time is needed for the effects of musical training to reverberate in motor and cognitive conditions, as the studies used different “dosages”. However, it can be inferred that we have a certain degree of evidence that a month of daily musical practice can have positive effects, mainly on levels of brain reorganization (Amengual et al., 2013, Carpentier, Moreno, McIntosh, 2016).

Musical training and cognition

Some studies have more directly assessed the effects of musical training on cognitive variables. In the study by (Cheung, Chan, Liu, Law, Wong, 2017), a group with musical training and one without was compared, it was found that the musical training group had a significant improvement in verbal memory. This corroborates the data from (Bergman Nutley, Darki & Klingberg, 2013) who found that practicing

music is associated with better performance in reasoning, working memory and mathematics tests. And finally, as previously mentioned, the study by (Wirth et al., 2021) verified that this superiority can be maintained in senility, because, when comparing a group of music practitioners and another group of non-practitioners at an advanced age, there is an advantage in global cognition, memory work and executive functions. This fact suggests a tendency for effects to be maintained in the medium and long term.

Musical Training versus Second Language Learning

Recently, two studies evaluated the comparison between musical training and non-native language learning (Carpentier, Moreno, McIntosh, 2016, Tervaniemi et al., 2021). The results differed, in the study of (Tervaniemi et al., 2021) the learning of a new language seemed to cause more effects on auditory processes early predictive auditory processes than musical training. On the other hand, in the research by (Carpentier, Moreno, McIntosh, 2016), which compared a musical practice group and another French learning group regarding the complexity of the EEG signal, it was found that the music group had an increase in the complexity of the EEG, a fact that occurred minimally in the French group. Therefore, it is not possible to say which model is more effective. Especially because the learning processes are distinct and their transfer effects are probably particular even though they have similarities in some variables.

Discussion

The present review provided an updated overview of the last 10 years regarding the effects of musical training specifically. In the literature there is a growing production involving music therapy and music-based interventions for motor (Braun Janzen, Koshimori, Richard, Thaut, 2022; Fan, Hu, Hey, Hu, 2023; Rusowicz, Szczepańska-Gieracha, Kiper, 2022; Xiong, Liao, Xiao, Bai, 2022; Lee & Ko, 2023),

cognitive (Ito, Nouchi, Dinet, Cheng, 2022; Lyu et al., 2018; Bian et al., 2021) and emotional (Zhang et al., 2017; Moreno-Morales, Calero, Moreno-Morales & Pintado, 2020; Chu et al., 2014) treatment. Such procedures have evidence of producing benefits in communication, cognition and well-being in populations with pathologies according to systematic reviews (Geretsegger et al., 2022; Liu et al., 2022; de Witte et al., 2022; Bleibel et al., 2023; de Witte, Pinho, Stams, Moonen, Bos & van Hooren, 2022; Bleibel, El Cheikh, Sadier & Abou-Abbas, 2023).

In this review we set out to elucidate concrete evidence about musical training itself. Music therapy and music-based interventions have their own developments and techniques that are sometimes relatively difficult to normalize. On the other hand, systematic musical training is an accessible and replicable procedure.

One of the possible effects of musical training is its correlation and possible influence on the cognitive development of children, so that early exposure to this intervention could optimize their general reasoning. Some studies set out to evaluate this relationship between musical education and indicators of intelligence and cognition and, like the studies already mentioned above, they found a positive correlation between such interactions ((Lima et al., 2022; Schellenberg, 2011; Hille, Gust, Bitz, Kammer, 2011).

From the point of view of motor benefits, the study by (a Silva et al., 2022) demonstrated that the motor capacity of children who had musical training was significantly better than that of children who did not have it. Having superior results in balance, temporal orientation and general motor quotient, which corroborates the study by (11) mentioned previously. Although the movements required in musical training are specific to the instrument and require a certain amplitude and limited movement, coordination, rhythm and body perception of space are essential for performing melodies assertively. This requirement is possibly reflected in non-musical motor skills with similar demands, leading to improved motor performance as a whole (da Silva et al., 2022; Moumdjian, Sarkamo, Leone, Leman & Feys, 2017; Prinz, Schumacher & Witte, 2023).

There are a number of studies that attempt to identify and reflect genetic influences on music aptitude (Tan, McPherson, Peretz, Berkovic & Wilson, 2014; Wesseldijk, Ullén & Mosing, 2023; Centanni, Anchan, Beard, Brooks, Thompson & Petrill, 2019; Wang, 2022), such studies correlate some innate conditions that can influence and even determine involvement with music. However, even with these genetic factors to be considered, even if, in hypothesis, maximum fitness is interfered by other factors, exposure to musical training can induce neuroplastic processes, thinking about the development and recovery/maintenance of cognitive and motor performance, this already is of great value (Neves, Correia, Castro, Martins & Lima, 2022; Moniz, Dias, Ribeiro, Glória & Boschi, 2020).

The evidence that musical training produces beneficial effects is still fairly sparse and unstandardized. More studies are needed, which in addition to an evaluation with a control group and intervention group, carry out collections prior to the interventions to define a baseline with the musical training group. It is also necessary to describe musical protocols in detail to ensure greater replicability.

Final considerations

Current literature demonstrates a trend toward significant benefits from musical training, whether in cognitive factors such as general executive functions, working memory, verbal and mathematical memory. As well as changes at brain levels, such as greater excitability, gray matter volume and intra-hemispheric coherence.

From this perspective, musical training becomes an option to complement physiotherapeutic treatment in patients after brain damage, being particularly interesting in those who have never had such an experience. In a context where common actions are no longer done in the usual way, learning a new skill can be particularly motivating.

Although there have been a fair number of studies evaluating musical training recently, standardized studies that determine causality between musical training and neurobehavioral changes are needed.

Conflict of interests

The authors declare that there are no conflicts of interest

Referências

Amengual JL, Rojo N, Veciana de Las Heras M, Marco-Pallarés J, Grau-Sánchez J, Schneider S, Vaquero L, Juncadella M, Montero J, Mohammadi B, Rubio F, Rueda N, Duarte E, Grau C, Altenmüller E, Münte TF, Rodríguez-Fornells A. Sensorimotor plasticity after music-supported therapy in chronic stroke patients revealed by transcranial magnetic stimulation. *PLoS One*. 2013 Apr 17;8(4):e61883. doi: 10.1371/journal.pone.0061883. PMID: 23613966; PMCID: PMC3629163.

Bergman Nutley S, Darki F, Klingberg T. Music practice is associated with development of working memory during childhood and adolescence. *Front Hum Neurosci*. 2014 Jan 7;7:926. doi: 10.3389/fnhum.2013.00926. PMID: 24431997; PMCID: PMC3882720.

Bian X, Wang Y, Zhao X, Zhang Z, Ding C. Does music therapy affect the global cognitive function of patients with dementia? A meta-analysis. *NeuroRehabilitation*. 2021;48(4):553-562. doi: 10.3233/NRE-210018. PMID: 33967069.

Bleibel M, El Cheikh A, Sadier NS, Abou-Abbas L. The effect of music therapy on cognitive functions in patients with Alzheimer's disease: a systematic review of randomized controlled trials. *Alzheimers Res Ther*. 2023 Mar 27;15(1):65. doi: 10.1186/s13195-023-01214-9. PMID: 36973733; PMCID: PMC10041788.

Bonassi, G., Lagravinese, G., Bove, M., Bisio, A., Botta, A., Putzolu, M., ... & Avanzino, L. (2023). How Music Moves Us: Music-induced Emotion Influences Motor Learning. *Neuroscience*, 526, 246-255.

Braun Janzen T, Koshimori Y, Richard NM, Thaut MH. Rhythm and Music-Based Interventions in Motor Rehabilitation: Current Evidence and Future Perspectives. *Front Hum Neurosci*. 2022 Jan 17;15:789467. doi: 10.3389/fnhum.2021.789467. PMID: 35111007; PMCID: PMC8801707.

Carpentier SM, Moreno S, McIntosh AR. Short-term Music Training Enhances Complex, Distributed Neural Communication during Music and Linguistic Tasks. *J Cogn Neurosci*. 2016 Oct;28(10):1603-12. doi: 10.1162/jocn_a_00988. Epub 2016 May 31. PMID: 27243611; PMCID: PMC5023326.

Centanni TM, Anchan DM, Beard M, Brooks R, Thompson LA, Petrill SA. Genetic and Environmental Influences on Decoding Skills - Implications for Music and Reading. *Front Psychol*. 2019 Nov 19;10:2604. doi: 10.3389/fpsyg.2019.02604. PMID: 31798510; PMCID: PMC6877899.

Chan, M. M., & Han, Y. M. (2022). The functional brain networks activated by music listening: A neuroimaging meta-analysis and implications for treatment. *Neuropsychology*, 36(1), 4.

Cheung MC, Chan AS, Liu Y, Law D, Wong CW. Music training is associated with cortical synchronization reflected in EEG coherence during verbal memory encoding. *PLoS One*. 2017 Mar 30;12(3):e0174906. doi: 10.1371/journal.pone.0174906. PMID: 28358852; PMCID: PMC5373634.

Chu H, Yang CY, Lin Y, Ou KL, Lee TY, O'Brien AP, Chou KR. The impact of group music therapy on depression and cognition in elderly persons with dementia: a randomized controlled study. *Biol Res Nurs*. 2014 Apr;16(2):209-17. doi: 10.1177/1099800413485410. Epub 2013 May 2. PMID: 23639952.

da Silva KS, Luvizutto GJ, Bruno ACM, de Oliveira SF, Costa SC, da Silva GM, Andrade MJC, Pereira JM, Andrade AO, de Souza LAPS. Gamma-Band Frequency Analysis and Motor Development in Music-Trained Children: A Cross-Sectional Study. *J Mot Behav*. 2022;54(2):203-211. doi: 10.1080/00222895.2021.1940820. Epub 2021 Jul 8. PMID: 34233603.

de Witte M, Pinho ADS, Stams GJ, Moonen X, Bos AER, van Hooren S. Music therapy for stress reduction: a systematic review and meta-analysis. *Health Psychol Rev*. 2022 Mar;16(1):134-159. doi: 10.1080/17437199.2020.1846580. Epub 2020 Nov 27. PMID: 33176590.

Esfidani, M. R., Rafiei Samani, S., & Khanlari, A. (2022). Music and consumer behavior in chain stores: theoretical explanation and empirical evidence. *The International Review of Retail, Distribution and Consumer Research*, 32(3), 331-348.

Fan L, Hu EY, Hey GE, Hu W. Music Therapy for Gait and Speech Deficits in Parkinson's Disease: A Mini-Review. *Brain Sci.* 2023 Jun 25;13(7):993. doi: 10.3390/brainsci13070993. PMID: 37508925; PMCID: PMC10377381.

Gaser, C. & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *J Neurosci* 23, 9240–9245

Geretsegger M, Fusar-Poli L, Elefant C, Mössler KA, Vitale G, Gold C. Music therapy for autistic people. *Cochrane Database Syst Rev.* 2022 May 9;5(5):CD004381. doi: 10.1002/14651858.CD004381.pub4. PMID: 35532041; PMCID: PMC9082683.

Gleichmann DC, Pinner JFL, Garcia C, Hakeem JH, Kodituwakku P, Stephen JM. A Pilot Study Examining the Effects of Music Training on Attention in Children with Fetal Alcohol Spectrum Disorders (FASD). *Sensors (Basel).* 2022 Jul 28;22(15):5642. doi: 10.3390/s22155642. PMID: 35957202; PMCID: PMC9370928.

Hille K, Gust K, Bitz U, Kammer T. Associations between music education, intelligence, and spelling ability in elementary school. *Adv Cogn Psychol.* 2011;7:1-6. doi: 10.2478/v10053-008-0082-4. Epub 2011 Mar 4. PMID: 21614212; PMCID: PMC3101523.

Hoekner, B., Wyatt, E. W., Decety, J., & Nusbaum, H. (2011). Film music influences how viewers relate to movie characters. *Psychology of Aesthetics, Creativity, and the Arts*, 5(2), 146.

Ito E, Nouchi R, Dinet J, Cheng CH, Husebø BS. The Effect of Music-Based Intervention on General Cognitive and Executive Functions, and Episodic Memory in People with Mild Cognitive Impairment and Dementia: A Systematic Review and Meta-Analysis of Recent Randomized Controlled Trials. *Healthcare (Basel).* 2022 Aug 3;10(8):1462. doi: 10.3390/healthcare10081462. PMID: 36011119; PMCID: PMC9408548.

Killin, A. (2018). The origins of music: Evidence, theory, and prospects. *Music & Science*, 1. <https://doi.org/10.1177/2059204317751971>

Lee H, Ko B. Effects of Music-Based Interventions on Motor and Non-Motor Symptoms in Patients with Parkinson's Disease: A Systematic Review and Meta-Analysis. *Int J Environ Res Public Health*. 2023 Jan 6;20(2):1046. doi: 10.3390/ijerph20021046. PMID: 36673802; PMCID: PMC9859027.

Lima RA, Soares FC, van Poppel M, Savinainen S, Mäntyselkä A, Haapala EA, Lakka T. Determinants of Cognitive Performance in Children and Adolescents: A Populational Longitudinal Study. *Int J Environ Res Public Health*. 2022 Jul 23;19(15):8955. doi: 10.3390/ijerph19158955. PMID: 35897325; PMCID: PMC9331797.

Liu Q, Li W, Yin Y, Zhao Z, Yang Y, Zhao Y, Tan Y, Yu J. The effect of music therapy on language recovery in patients with aphasia after stroke: a systematic review and meta-analysis. *Neurol Sci*. 2022 Feb;43(2):863-872. doi: 10.1007/s10072-021-05743-9. Epub 2021 Nov 24. PMID: 34816318.

Loui P, Raine LB, Chaddock-Heyman L, Kramer AF and Hillman CH (2019) Musical Instrument Practice Predicts White Matter Microstructure and Cognitive Abilities in Childhood. *Front. Psychol*. 10:1198. doi: 10.3389/fpsyg.2019.01198

Lyu J, Zhang J, Mu H, Li W, Champ M, Xiong Q, Gao T, Xie L, Jin W, Yang W, Cui M, Gao M, Li M. The Effects of Music Therapy on Cognition, Psychiatric Symptoms, and Activities of Daily Living in Patients with Alzheimer's Disease. *J Alzheimers Dis*. 2018;64(4):1347-1358. doi: 10.3233/JAD-180183. PMID: 29991131.

Martins M, Neves L, Rodrigues P, Vasconcelos O and Castro SL (2018) Orff-Based Music Training Enhances Children's Manual Dexterity and Bimanual Coordination. *Front. Psychol*. 9:2616. doi: 10.3389/fpsyg.2018.02616

Mithen, S. (2009), *The Music Instinct*. *Annals of the New York Academy of Sciences*, 1169: 3-12. <https://doi.org/10.1111/j.1749-6632.2009.04590.x>

Moniz YM, Dias DR, Ribeiro LC, Glória IP, Boschi SR. (2020). PROPOSTA DE TREINAMENTO MUSICAL PARA ESTIMULAR A MELHORA DE COORDENAÇÃO MOTORA EM CRIANÇAS

E ADOLESCENTES COM ALTERAÇÕES MOTORAS. *Revista Científica UMC*, 5(3). Recuperado de <https://seer.umc.br/index.php/revistaumc/article/view/1458>

Moreno-Morales C, Calero R, Moreno-Morales P, Pintado C. Music Therapy in the Treatment of Dementia: A Systematic Review and Meta-Analysis. *Front Med (Lausanne)*. 2020 May 19;7:160. doi: 10.3389/fmed.2020.00160. PMID: 32509790; PMCID: PMC7248378.

Moumdjian L, Sarkamo T, Leone C, Leman M, Feys P. Effectiveness of music-based interventions on motricity or cognitive functioning in neurological populations: a systematic review. *Eur J Phys Rehabil Med*. 2017 Jun;53(3):466-482. doi: 10.23736/S1973-9087.16.04429-4. Epub 2016 Nov 23. PMID: 27879960.

Neves L, Correia AI, Castro SL, Martins D, Lima CF. Does music training enhance auditory and linguistic processing? A systematic review and meta-analysis of behavioral and brain evidence. *Neurosci Biobehav Rev*. 2022 Sep;140:104777. doi: 10.1016/j.neubiorev.2022.104777. Epub 2022 Jul 14. Erratum in: *Neurosci Biobehav Rev*. 2023 Dec;155:105442. PMID: 35843347.

Prinz A, Schumacher A, Witte K. Changes in Selected Cognitive and Motor Skills as Well as the Quality of Life After a 24-Week Multidimensional Music-Based Exercise Program in People With Dementia. *Am J Alzheimers Dis Other Demen*. 2023 Jan-Dec;38:15333175231191022. doi: 10.1177/15333175231191022. PMID: 37611012.

Rusowicz J, Szczepańska-Gieracha J, Kiper P. Neurologic Music Therapy in Geriatric Rehabilitation: A Systematic Review. *Healthcare (Basel)*. 2022 Oct 31;10(11):2187. doi: 10.3390/healthcare10112187. PMID: 36360527; PMCID: PMC9690210.

Schellenberg EG. Examining the association between music lessons and intelligence. *Br J Psychol*. 2011 Aug;102(3):283-302. doi: 10.1111/j.2044-8295.2010.02000.x. Epub 2011 Feb 1. PMID: 21751987.

Taheri S, Razeghi M, Choobineh A, Kazemi R, Rasipisheh P, Vali M. Investigating the effect of background music on cognitive and skill performance: A cross-sectional study. *Work*. 2022;71(4):871-879. doi: 10.3233/WOR-213631. PMID: 35253719.

Tan YT, McPherson GE, Peretz I, Berkovic SF, Wilson SJ. The genetic basis of music ability. *Front Psychol*. 2014 Jun 27;5:658. doi: 10.3389/fpsyg.2014.00658. PMID: 25018744; PMCID: PMC4073543.

Tervaniemi M, Putkinen V, Nie P, Wang C, Du B, Lu J, Li S, Cowley BU, Tammi T, Tao S. Improved Auditory Function Caused by Music Versus Foreign Language Training at School Age: Is There a Difference? *Cereb Cortex*. 2021 Nov 23;32(1):63-75. doi: 10.1093/cercor/bhab194. PMID: 34265850; PMCID: PMC8634570.

Ullén F, Mosing MA, Madison G. Associations between motor timing, music practice, and intelligence studied in a large sample of twins. *Ann N Y Acad Sci*. 2015 Mar;1337:125-9. doi: 10.1111/nyas.12630. PMID: 25773626.

Wang L. Music Aptitude, Training, and Cognitive Transfer: A Mini-Review. *Front Psychol*. 2022 Jun 29;13:903920. doi: 10.3389/fpsyg.2022.903920. PMID: 35846628; PMCID: PMC9277581.

Wesseldijk LW, Ullén F, Mosing MA. Music and Genetics. *Neurosci Biobehav Rev*. 2023 Sep;152:105302. doi: 10.1016/j.neubiorev.2023.105302. Epub 2023 Jul 1. PMID: 37400010.

Wirth, M., Böttcher, A., Höppner, A., Fabel, K., Köbe, T., Teipel, S.J., Peters, O., Priller, J., Schneider, A., Wiltfang, J., Buerger, K., Pernecky, R., Laske, C., Spottke, A., Jessen, F., Düzel, E., Wagner, M. and Roeske, S. (2021), Lifelong music practice as reserve factor: Associations with cognition and brain structure in older adults. *Alzheimer's Dement.*, 17: e055411. <https://doi.org/10.1002/alz.055411>

Xiong F, Liao X, Xiao J, Bai X, Huang J, Zhang B, Li F, Li P. Emerging Limb Rehabilitation Therapy After Post-stroke Motor Recovery. *Front Aging Neurosci*. 2022 Mar 23;14:863379. doi: 10.3389/fnagi.2022.863379. PMID: 35401147; PMCID: PMC8984121.

Zhang Y, Cai J, An L, Hui F, Ren T, Ma H, Zhao Q. Does music therapy enhance behavioral and cognitive function in elderly dementia patients? A systematic review and meta-analysis. *Ageing Res Rev.* 2017 May;35:1-11. doi: 10.1016/j.arr.2016.12.003. Epub 2016 Dec 23. PMID: 28025173.

Zhang, J., Xiao, X., & Lee, Y. (2004). The early development of music. Analysis of the Jiahu bone flutes. *Antiquity*, 78(302), 769-778. doi:10.1017/S0003598X00113432