THE RELATIONSHIP OF MUSICAL PERCEPTION AND THE EXECUTIVE FUNCTION AMONG 7-YEAR-OLD CHILDREN

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Abstract

There is ample research to support that learning music has a positive effect on cognitive development and school success. In recent years, the focus of the research has shifted to exploring the relationship between music training and the executive functions (which main dimensions are working memory, inhibitory control and cognitive flexibility). As a result, there is evidence to confirm that music learning has a positive effect on the development of the executive functions. However, no empirical data is available about the relationship of simple musical activities and the executive functions. From an educational point of view, it would be essential to know the strength of the relationship between the development of the executive functions and the level of development of the various musical skills, but no research has examined it before.

This research study is aimed at exploring the relationship of musical perception and the executive function at the beginning of formal education. Participants were 131 first-grade students from 6 different classes. Their average age was 7 years and 2 months. 51% of the participants were boys. Children were educated in line with the Hungarian National Core Curriculum. Tests were administered via tablets as Android applications. The executive function was measured with the FOCUS test. Significant correlation was found between the executive function and musical perception ($r=.29$, $p=.002$). The correlation of pitch perception and the executive function ($r=.19$, $p=.03$) and the correlation of time perception and the executive function ($r=.25$, $p=.007$) were also found to be significant. No significant difference was found between the strength of the correlations. The research provides evidence that musical perception is linked to the development of the executive function in children. Results suggest that even less complex musical activities used in the first year of formal education may contribute to the development of the executive function. However, more research is needed to confirm the role of transfer.

Keywords: executive function, musical perception, digital devices.

1 INTRODUCTION

1.1 Executive functions and music training

The comprehensive role of music training on cognitive development and learning at school has been confirmed by previous research [1]. Among others, musical activities have a positive effect on early reading skills and phonological processing in pre-readers and kindergarten-age children ([2], [3]) as well as on the development of reading ([4], [5]), arithmetic skills ([6], [7]) and intelligence ([8], [9]). In recent years, research concerning the relationship of music learning and the executive functions has also focused on examining the intermediary role of the latter; far transfer between music and other cognitive areas is possible through the development of the executive functions ([10], [11]). Executive functions are responsible for the conscious control of thought and behavior. These processes include the working memory, inhibitory control and cognitive flexibility, which can be interpreted as the cognitive sub-components of a larger self-regulatory construct ([12], [13]). There is also evidence that high-level functioning of the executive functions underlie processes like attention, cognition and problem-solving, which play an essential role in school performance ([14], [15]).

Playing an instrument and music learning are complex activities requiring systematic, daily practice. Learning to read music is a must in this process. Learning to play an instrument includes memorizing extensive music sequences, learning and playing various music structures (intervals, scales, chords, chord progressions). It entails continuous acquisition of technical (motor) skills as well as learning to express emotions in a controlled manner [16]. This requires focused attention for longer periods as well as shifting of attention and continuous planning and control. Thus, playing an instrument is typically an activity, which requires high-level cognitive control, including planning and regulation of cognition and behavior (e.g. [17], [18]).

Correlational studies examining musicians have confirmed a positive relationship between cognitive flexibility and music training (on the Trail-Making Test: [19]; in cued task-switching: [20]). Music training may lead to more general advantages in inhibitory control (pitch-based auditory Stroop task: [21]; on stop-signal task: [22]). Moreover, sight reading investigations have confirmed that working memory improves as a result of music training ([23], [24], [25]).

Relatively small but growing experimental investigations are examining the effects of music training programs on EF abilities. The majority of these studies also suggests that taking music lessons may enhance EF performance. Bugos, Perlstein, McCrae, Brophy and Bedenbaugh [26] have found that the cognitive flexibility of 31 adults (aged 60 to 85 years) have improved after taking weekly piano lessons for six month. Portowitz, Peppler and Downton [27] have also confirmed an improvement in the cognitive flexibility, self-regulation and working memory of 62 children (9- to 10-year old) from the United States and Israel who participated in the Harmony program. This program is based on the components of Feuerstein's theory of structural cognitive modifiability and mediated learning experiences [28] and Diamond's theory of executive functions [29]. Another computerized music training program, in which children learned about basic musical concepts like pitch and rhythm, has also established the positive effect on the EF component of inhibitory control [30]. Improvement of the working memory (counting span test and a complex span test) among 7-8 year-old children has been found after 18 months of weekly music lessons on an instrument [31].

The longitudinal study results of Jaschke, Honing and Erik [10] have also indicated the positive influence of long-term music education on cognitive abilities such as inhibition and planning. In this study, 146 primary school children were followed for 2.5 years. Participants were randomized into four groups, two music intervention groups, one active visual arts group, and a no arts control group. Significant improvements were found with regard to inhibition and planning as well as verbal IQ after two-and-a-half years of music intervention. Additionally, children in the visual arts group performed better on visuospatial memory tasks as compared to the three other groups. Results show a possible far transfer effect from a structured music education program to academic achievement, mediated through executive sub-functions.

However, some results do not confirm the positive effect of music lessons on cognitive development. For example, in their longitudinal study, Rickard, Bambrick, and Gill [32] have not found significant differences in the verbal memory test results of 10-13-year-old children who participated in classroom-based group music lessons or drama or art lessons. Similarly, Schellenberg [33] has not found a relationship between music lessons and the results on the Phonological Fluency, the Sun-Moon Stroop, the Tower of Hanoi, and the Wisconsin Card Sorting Test.

Hargreaves and Aksentievic highlight that the extent to which the intercorrelations between the presence/absence of music lessons and measures of EF and IQ might also be influenced by musical aptitude is also important to consider [34]. However, no empirical data is available about the relationship of musical perception and the executive functions.

1.2 Musical perception

Listening to music as well as composing music engages a large array of psychological processes, including perception and multimodal integration, attention, learning and memory, syntactic processing and processing of meaningful information, action, emotion, and social cognition ([35]. In a wider sense, musical skills also cover the special skills that take part in the process of interpretation, listening to music or composing music. In a narrower sense, however, musical skills are the skills that fully relate to musical content. These include the perception of the acoustical properties of music as well as the perception and reproduction of pitch and time. All complex musical skills are based on musical perception, which is based on cognitive operations that take part in auditive information processing. Musical perception is the basis of all musical activities like musical instrument play, which development is determined by certain universal aspects of musical structure as well as by the environment [36]. According to the modular theory of musical perception [37], pitch and time perception are distinct from each other and develop differently. Therefore, their level of development should be examined separately, while also examining the developmental level of musical perception organically.

There are three important musical pattern properties with regard to pitch-based perception: pitch, melody and harmony. Recognizing melodic contour, the sequence of motions between notes of a melody is an important property in the perception of melody. The development of tonal sense is influenced by culture, infants are receptive to the vocal system of any culture [38]. Key membership,

the ability to decide whether a specific sound of the chromatic scale belongs to a specific key, plays an important role in the perception of harmony. In Western music, this entails tonal hierarchy and identifying harmony changes also plays an important role. Rhythmic organization is the product of two independent hierarchical structures, grouping and meter. Grouping means that smaller units are organized into bigger ones, which are organized into even bigger ones. Meter also entails the creation of hierarchy by the regularly recurring patterns and accents [39].

The perception dimensions examined by musical ability research has mainly focused on pitch and time properties, either on their own such as pitch or rhythm perception, or as a combination of pitch and time such as melody perception. Musical aptitude tests typically examine the perception of melody, rhythm, pitch, chords, timbre, volume, meter and tempo. In other words, musical aptitude tests are concerned with the musical potential of the individual, they measure the level of development of musical skills independent of one's previous knowledge. Musical achievement tests measure musical knowledge, singing or instrumental performance. Previous results indicate a significant correlation between the successfulness on general intelligence tests and musical aptitude tests. The correlation coefficient is usually around 0.30. The relationship of IQ and musical achievement tests is even stronger [40].

Musical aptitude tests are based on same-different tasks. The level of performance in same-different tasks, in which participants have to judge whether two sequences of sounds are the same or different, is linked to the ability to maintain several sounds in the working memory [41]. Completing these tests may require other EF components as well like inhibitory control or cognitive flexibility. Degé, Kubicek & Schwarzer [42] confirmed a significant correlation between working memory and rhythm perception and production. From rhythmic skills, perception showed a stronger relationship.

As the literature review suggests, music learning may have a positive effect on the development of the executive functions. Research in the field has mainly concentrated one or more components of EF. However, to the best of our knowledge, no research or measurement instrument have examined the executive function as a complex unit. Furthermore, while a number of empirical studies have explored the effects of music learning on the development of the various components of the executive function, its relationship to musical perception, which underlies all musical activities, has received little attention. Musical aptitude, as measured by instruments, starts to develop at the start of formal education, and compared to musical instrument playing, it is less complex. From an educational point of view, it would be essential to know the strength of the relationship between the development of the executive functions and the level of development of musical perception. This research study is aimed at exploring the relationship of musical perception and the executive function at the beginning of formal education.

2 METHODOLOGY

2.1 Participants

Data collection took place in May, 2018, at the end of the academic year. Participants were 131 first-grade students from six classes. Their average age was 7 years and 2 months. 51% of the participants were boys. Children were educated in line with the Hungarian National Core Curriculum, which heavily relies on the Kodály method. Students had 45-minute music classes twice a week, musical instrument play was not part of their education.

2.2 Measures

2.2.1 Musical perception test

The musical perception test consisted of two subtests: pitch perception (22 items Cronbach's α: .78), and time perception 12 items (Cronbach's α: .71). The first section includes three tasks (a) melody, (b) pitch perception and (c) chord analysis. The second part has two tasks rhythm discrimination and tempo discrimination (Figure 1). The overall reliability of the test was high (Cronbach's α: .84) [43].

The test was administered on the online eDia system of the University of Szeged. Students completed the tasks on PCs using headphones. Instructions were given in audio files. Students were allowed to listen to the audio instructions more than once, however, once they started completing the tasks, they could not return to these audio instruction files. Test completion required 25 minutes on average.

Figure 1. Screen shots of the melody and rhythm discrimination (same-different), the chord analysis (one or more sounds), the tempo discrimination (slower-faster) and the pitch discrimination (higher-lower) tasks [44].

2.2.2 Executive function test

The FOCUS (Finding Out Children's Unique Strengths) computer-tablet tasks were designed to assess mastery motivation, pre-academic knowledge, and executive functions in 3-8 year-old children in Hungary and the U.S. as a school readiness predictor ([44], [45]). There are two *executive function tasks,* the *Picture Memory* and the *Size-Shape-Color Game*. Each child was given six tasks, three for Picture Memory and three for *Size-Shape-Color Game*. For both types of tasks, one level was assumed to be easy, one was assumed to be moderately difficult, and one was assumed to be very challenging, based on children's age.

The Picture Memory task measures the working memory. The child looks at a rectangular array of blank cards, which have pictures on the other side. When the child touches a blank card, the computer turns it over so that the picture becomes visible. The Size-Shape-Color Game (which is based on the Dimensional Change Card Sort task; [46]), requires two other EFs: self-regulated inhibition and mental set shifting. Self-regulated inhibition enables children to inhibit attention to irrelevant information and to prevent themselves from exhibiting undesired but dominant responses. It therefore helps children regulate impulses so a goal can be achieved. Mental set shifting allows the child to follow changing or conflicting rules during problem solving. Like the Dimensional Change Card Sort (DCCS) task, the Size-Shape-Color Game requires the child not only to remember (or figure out) the sorting rules but also to respond to multiple rule changes on multiple sorting dimensions, and to inhibit responses consistent with previous rules (Figure 2).

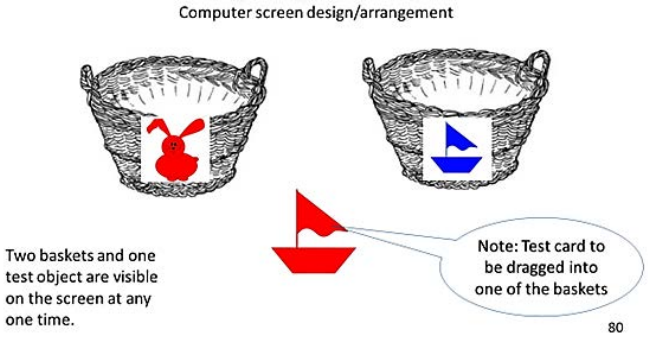

Figure 2. The general design of the screen for the dimensional change card sort tasks. For levels 1–6, there are two baskets and one test object or card on the screen at any one time [44].

3 RESULTS

We assessed two factors of music perception, and also two factors of executive function in this study. Moderate significant correlation (r=.33, p<.01) was found between the time and pitch dimensions of musical perception. The correlation between the two dimensions of the executive function was also moderate (r=.28, p=.029).

The primary aim of the study was to examine the relationship between musical perception and the executive function. Significant correlations were found between the card sorting test and musical perception as well as between the time and pitch dimensions (Table 1). Moderate correlation (r=.29, p=.002) was found between the card sorting total score and musical perception. The correlations were weak between the executive function and the two dimensions of musical perception (time dimension: r=.25. p=.03; pitch dimension: r=.19, p=.007). The easy card sorting task had a weak correlation (r=.24, p=.03) with musical perception. The strongest, moderate correlation (r=.53, p<.001) was found between the moderately challenging card sorting tasks and musical perception. The correlation with the pitch

dimension was moderate as well (r=.49, p<.001), while it was significantly weaker but significant with the time dimension (r=.36, p=.004). With regard to hard card sorting tasks and musical abilities, only the time dimension showed a significant correlation (r=.26, p=.004) (Table 1). The differences between the strength of the correlations are probably explained by the fact that moderately challenging card sorting tasks differentiate more than easy and hard tasks. The standard deviation of the easy picture memory task was nearly zero, this task was very easy for the children. That is why the correlations of this variable are very low.

Table 1. Correlations among the executive function tasks, the total test and musical perception, timing perception and pitch perception.

Executive function	Musical perception	Time dimension	Pitch dimension
Picture memory - easy	.02	.01	.00
Picture memory - moderate	.20*	.21*	.08
Picture memory - hard	.13	.16	.11
Picture memory – total	.20*	.17	.17
Card sorting - easy	.24*	.21	.16
Card sorting - moderate	.53**	.36**	.49**
Card sorting - hard	.16	.28*	.05
Card sorting - total	.25*	.28*	.05
Executive function - total	*.29***	*.25***	*.19**

*p<.05, **p<.01

Out of the musical abilities, rhythm discrimination showed the strongest correlation with the total score of the executive function (r=.32, p<.001). The correlations were significant but weaker for melody discrimination (r=.25, p=.004) and chord analysis (r=.18, p=.046). Tempo and pitch discrimination did not have significant correlations with the total score of the executive function. Pitch discrimination 1. had significant correlations with the hard picture memory tasks and the easy card sorting tasks (picture memory total: r=.31, p=.013; card sorting - easy: r=.27, p=.030). Challenging picture memory has a significant correlation with melody discrimination (r=.26, p=.016). The moderately challenging card sorting task correlated with the pitch discrimination task (r=.38, p=.002).

Musical abilities had the strongest correlation with the moderately challenging card sorting task. The moderately challenging card sorting total score had the strongest correlation with melody discrimination (r=.45, p<.001). The correlation of for the chord analysis task suggested a moderate relationship with the card sorting total score (r=.44, p<.001). The only significant correlation for tempo discrimination was with moderately challenging card sorting tasks (tempo total: r=.31, p=.014). Whereas for the challenging card sorting task, the only significant correlation was with musical perception, r=.28 (p=.028) (Table 2).

Table 2. Correlations among the executive function tasks, the total test and the music perception abilities.

Executive function	Rhythm discr.	Tempo discr.	Melody discr.	Pitch discr. 1.	Pitch discr. 2	Chord analysis
Picture memory - easy	.02	.01	.00	.02	.01	.00
Picture memory – moderate	.09	.20	.26*	.10	.06	.11
Picture memory - hard	.20*	.16	.17	.21*	.11	.04
Picture memory – total	.20*	.12	.15	.31*	.03	.02
Card sorting - easy	.20	.08	.23	.27*	.14	.01
Card sorting – moderate	.27*	.31*	.45**	.38**	.26*	.44**
Card sorting - hard	.28**	.17	-.02	.03	-.09	.06
Card sorting – total	.24*	.21*	.28**	.21*	.17	.21**
Executive function - total	*.32***	*.14*	*.25***	*.11*	*.16*	*.18**

*p<.05, **p<.01

4 CONCLUSIONS

This study focused on the relationship between the executive function and musical perception. Both areas were measured online via computer-assisted instruments. The FOCUS test [44] measures the executive function in a complex manner. The main dimensions of the musical perception test [46] are timing and pitch. Both instruments were adapted; their reliability was appropriate in the study.

Our results confirmed the relationship between the executive function and musical perception. Previous studies have mainly focused on the positive effects of experimental programs, which included learning to play an instrument, on the development of one or more components of the executive function (cognitive flexibility, self-regulation or working memory). Quasi-experimental studies have showed the benefits of learning to play an instrument in the operation of the various components of the executive function (see the reviews: [47], [48]). Furthermore, the experiment of Moreno, Bialystok, Barac, Schellenberg, Cepeda and Chau [30] has confirmed that musical activities that do not require playing an instrument also have a positive effect on the development of the executive function. A short, 20-day music training with preschool children has also led to improved performance in an executive-function task (the go/no-go task). This music curriculum was based on an interactive, computer-based training program (combination of motor, perceptual, and cognitive tasks and training in rhythm, pitch, melody, voice, and basic musical concepts). A number of musical and other skills take part in the process of playing an instrument. Among these other skills there are some essential cognitive skills that form the components of the executive functions [48]. We may assume that the relationship found by previous studies can be captured on a more simple level, through musical perception, that is the perception of music patterns (pitch, rhythm) [34]. However, no research has undertaken to carry out a complex examination of the relationship of the basic components of the executive function (working memory, inhibitory control and cognitive flexibility) and musical perception. Therefore, this research brings new insights by exploring the relatively simple but essential link between the executive function and musical perception.

Significant correlation was found between the level of development of the executive function and that of musical perception. From the two distinct areas of musical processing (time, pitch), time processing showed a stronger correlation with the executive function than pitch. From the musical skills examined, rhythm, pitch discrimination and chord analysis had significant correlations with the executive function.

With regard to the tasks of the executive function test, picture memory tasks, which measure the working memory, showed a weak but significant correlation with the aggregate index of musical perception as well as with the rhythm and pitch dimensions. The correlations relating to the difficulty level of tasks measuring the working memory suggested a significant correlation between the working memory and melody discrimination (r=.26) and pitch discrimination (r=.31). Contrary to this, from the subtests of musical perception, the results of Degé, Kubicek and Schwarzer [49] suggested a significant correlation between the working memory and rhythm perception.

The strongest, moderate correlation (r=.53) was found between the total index of the moderately difficult tasks of the Size-Shape-Color Game, which measured the self-regulated inhibition and mental set shifting components of the executive function, and musical perception. From the time and pitch dimensions of musical perception, the correlation with the pitch dimension was stronger and moderate, however, the correlation of the time dimension was also significant. From the high-level tasks of the Size-Shape-Color Game, only time processing had a significant correlation. From the musical perception test, musical skills again showed the strongest correlation with self-regulated inhibition and mental set shifting. From the skills relating to pitch processing, melody discrimination and chord analysis showed weak to moderate correlation with the total index. From the moderately difficult tasks, the first one had a significant correlation with all musical skills.

Musical aptitude tests are based on the perception of sameness-difference. The level of performance in these tasks is linked to the ability to maintain several sounds in the working memory [41]. The study confirmed that EF components like inhibitory control and cognitive flexibility (*self-regulated inhibition and mental set shifting)* play an important role in the process of completing these tests. Results provided evidence that there is a relationship between the general level of development of the executive function and that of musical perception. From the distinct areas of musical processing, rhythm perception showed a stronger correlation, however, the relationship is significant with pitch perception as well. The study also confirmed the significant correlation between the working memory and musical skills relating to pitch perception. Furthermore, evidence was found for the significant relationship of inhibitory control and cognitive flexibility, the components of the executive function, and

the pitch and time dimensions of musical perception and the general level of development of musical perception.

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REFERENCES

[1] E. G. Schellenberg, and E. Winner, “Music training and nonmusical abilities: Introduction”. *Music Perception,* vol. 29, no. 2, pp. 129–132, December 2011.

[2] S. H. Anvari, L. J. Trainor, J. Woodside, and B. A. Levy, “Relations among musical skills, phonological processing, and early reading ability in preschool children,” *Experimental Child Psychology*, vol. 83, pp. 111–130., 2002

[3] Z. F. Peynircioglu, A. Y. Durgunoglu and B. Oney-Kusefoglu, “Phonological awareness and musical aptitude,” Journal of Research in Reading vol. 25, no 1, pp. 68–80, 2002.

[4] R. Butzlaff, “Can music be used to teach reading?” *Journal of Aesthetic Education*, vol. 34, no. 3–4, pp. 167–178, 2000.

[5] S. Douglas, and P. Willatts, “The Relationship Between Musical Ability and Literacy Skills,” *J Res Read* vol.17. no 8., 1994.

[6] M. F. Gardiner, A. Fox, F. Knowles, D. Jeffery, “Learning Improved by Arts Training,” *Nature* vol. 381, no. 1, 1996.

[7] L. Hoch, B. Tillmann, “Shared structural and temporal integration resources for music and arithmetic processing,” *Acta Psychol* vol. 140, pp. 230–235, 2012.

[8] E. G. Schellenberg, “Music lessons enhance IQ,” *Psychological Science*, vol. 15, pp. 511–514, 2004.

[9] E. G. Schellenberg, “Long-term positive associations between music lessons and IQ,” *Journal of Educational Psychology*, vol. 98, no. 2, pp. 457–468, 2006.

[10] A. C. Jaschke, H. Honing, and E. J. A. Scherder, “Longitudinal Analysis of Music Education on Executive Functions in Primary School Children,” *Frontiers in Neuroscience*, 12, 2018. doi: 10.3389/fnins.2018.00103

[11] J. Zuk, C. Benjamin, A. Kenyon, and N. Gaab, “Behavioral and neural correlates of executive functioning in musicians and non-musicians,” *PloS One*, vol. 9, no. 6, 2014. doi:10.1371/journal.pone.0099868

[12] S. D. Calkins, and S. Marcovitch, “Emotion regulation and executive functioning in early development: Mechanisms of control supporting adaptive functioning,” in *Child development at the intersection of emotion and cognition* (S. D. Calkins, and M. A. Bell, eds.), pp. 37–57, Washington, DC. Jaschke: American Psychological Association, 2010.

[13] A. Miyake, N. P. Friedman, M. J. Emerson, A. H. Witzki, A. Howerter, and T. D. Wager, “The Unity and Diversity of Executive Functions and Their Contributions to Complex „Frontal Lobe” Tasks: A Latent Variable Analysis,” *Cognitive Psychology*, vol. 41, no. 1, pp. 49–100, 2000.

[14] L. B. Thorell, S. Lindqvist, S. B. Nutley, G. Bohlin, and T. Klingberg, “Training and transfer effects of executive functions in preschool children,” *Developmental Science*, vol. 12, no. 1, pp. 106–113, 2009.

[15] J. R. Best, P. H. Miller, and L. L. Jones, “Executive functions after age 5: Changes and correlates,” *Developmental Review*, vol. 29, no. 3, pp. 180–200., 2009.

[16] E. R. Huttenlocher, “Neural plasticity: The effects of environment on the development of the cerebral cortex,”. *Harvard University Press*, Cambridge, MA., 2002.

[17] A. Diamond, “Executive functions,” *Annual Review of Psychology*, vol. 64 no. 1, pp.135–168, 2013.

[18] A. Diamond, and D. Ling, “Review of the evidence on fundamental questions surrounding and efforts to improve executive functions (including working memory),” in *An integrative approach to cognitive and working memory training: Perspectives from psychology, neuroscience, and human development*, (M. Bunting, J. Novick, M. Dougherty, and R. W. Engle eds.), New York: Oxford University Press., 2017.

[19] B. Hanna-Pladdy, and A. MacKay, “The relation between instrumental musical activity and cognitive aging,” *Neuropsychology*, vol. 25, no. 3, pp. 378–386, 2011.

[20] L. Moradzadeh, G. Blumenthal, and M. Wiseheart, “Musical training, bilingualism, and executive function: A closer look at task switching and dual-task performance,” *Cognitive Science*, vol. 39, no. 5, pp. 992–1020, 2015.

[21] E. Bialystok, and A.-M. Depape, “Musical expertise, bilingualism, and executive functioning,” *Journal of Experimental Psychology: Human Perception and Performance*, vol. 35, no. 2, pp. 565–574, 2009.

[22] S. Moreno, Z. Wodniecka, W. Tays, C. Alain, and E. Bialystok, “Inhibitory control in bilinguals and musicians: Event related potential (ERP) evidence for experience-specific effects,” PLoS ONE, 9(4), e94169, 2014.

[23] E. J. Meinz, and D. Z. Hambrick, “Deliberate practice is necessary but not sufficient to explain individual differences in piano sight-reading skill: The role of working memory capacity,” *Psychological Science*, vol. 21, no. 7, pp. 914–919, 2010

[24] L. R. Slevc, N. S. Davey, M. Buschkuehl, and S. M. Jaeggi, “Tuning the mind: Exploring the connections between musical ability and executive functions,” *Cognition*, vol. 152, pp. 199-211, 2016.

[25] B. M. Okada, “Musical Training and Executive Functions,” *Master’s Thesis*, Available from Digital Repository at the University of Maryland. doi: http://hdl.handle.net/1903/18933, 2016.

[26] J. A. Bugos, W. M. Perlstein, C. S. McCrae, T. S. Brophy, and P. H. Bedenbaugh, “Individualized piano instruction enhances executive functioning and working memory in older adults,” *Aging & Mental Health,* vol. 11, no. 4, pp. 464–471, 2007.

[27] A. Portowitz, K. A. Peppler, and M. Downton, “In Harmony: A technology-based music education model to enhance musical understanding and general learning skills,” *International Journal of Music Education*, vol. 32, no. 2, pp. 242–260, 2014.

[28] R. Feuerstein, R. S. Feuerstein, L. Falik, and Y. Rand, “Creating and enhancing cognitive flexibility” *The Feuerstein Instrumental Enrichment Program*, Jerusalem, Israel: ICELP Press. , 2006.

[29] A. Diamond, “Supporting online material for preschool program improves cognitive control,” *Science*, vol. 317, pp. 1387, 2007. Doi: 10.1126/science.1151148, Retrievd from http://www.sciencemag.org/contetnt/318/5855/1387/suppl/DC1

[30] S. Moreno, E. Bialystok, R. Barac, E. G. Schellenberg, N. J. Cepeda, and T. Chau, “Short-term music training enhances verbal intelligence and executive function,” Psychological Science, vol. 22, no. 11, pp. 1425–1433, 2011.

[31] I. Roden, D. Grube, S. Bongard, and G. Kreutz, “Does music training enhance working memory performance? Findings from a quasi-experimental longitudinal study,” *Psychology of Music*, vol. 42, no. 2, pp. 284–298, 2014.

[32] N. S. Rickard, C. J. Bambrick, and A. Gill, “Absence of widespread psychosocial and cognitive effects of school-based music instruction in 10–13-year-old students,” *International Journal of Music Education*, vol. 30, no. 1, pp. 57–78, 2012.

[33] E. G. Schellenberg, “Examining the association between music lessons and intelligence,” *British Journal of Psychology*, vol. 102, no. 3, pp. 283–302, 2011.

[34] D. J. Hargreaves, and A. Aksentijevic, “Music, IQ, and the executive function,” *British Journal of Psychology*, vol. 102, pp. 306–308, 2011.

[35] S. Koelsch, *Brain and Music*, Chichester, UK: Wiley-Blackwell, 2012.

[36] E. E. Hannon, and L. J. Trainor, “Music acquisition: effects on enculturation and formal training on development,” *Trends in Cognitive Sciences*, vol. 11, no. 6, pp. 466–472, 2007.

[37] I. Peretz, and M. Coltheart, “Modularity of music processing,” *Nature Neuroscience*, vol. 6, no. 7, pp. 688–691, 2003.

[38] L. J. Trainor, and S. E. Trehub, “What mediates adults’ and infants’ superior processing of the major triad? Music Perception, vol. 11, no. 2, pp. 185–196, 1993.

[39] R. Jackendoff, and F. Lerdahl, “The capacity for music: What is it, and what’s special about it? *Cognition*, vol. 100, no. ….pp. 33–72, 2006.

[40] R. Shuter-Dyson, “Musical ability,” in *The psychology of music* (2nd ed.) (Deutsch D, ed.), San Diego, CA: *Academic Press*. pp. 627–651, 1999.

[41] C. Marie, F. Delogu, G. Lampis, M. Olivetti Belardinelli, and M. Besson, “Influence of musical expertise on segmental and tonal processing in Mandarin Chinese,” *Journal of Cognitive Neuroscience*, 2011. doi: 10.1162/jocn.2010.21585

[42] F. Dege, C. Kubicek, and G. Schwarzer, “Music lessons and intelligence: a relation mediated by executive functions,” *Music Percept* vol. 29, no. 2, pp. 195–201, 2011.

[43] N. Surján, and M. Janurik, “Examining the development of musical perception with traditional and computer-based testing,” *Gyermeknevelés*, vol. 6, no. 2, pp. 32–48, 2018.

[44] K. C. Barrett, K. Józsa, and G. A. Morgan, “New computer-based mastery motivation and executive function tasks for school readiness and school success in 3 to 8 year-old children,” *Hungarian Educational Research Journal*, vol. 7, no. 2, pp. 86–105, 2017.

[45] K. Józsa, K. C. Barrett, and G. A. Morgan, “Game-like Tablet Assessment of Approaches to Learning: Assessing Mastery Motivation and Executive Functions,” *Electronic Journal of Research in Educational Psychology*, vol. 15, no. 3, pp. 665–695, 2017.

[46] P. D. Zelazo, “The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children,” *Nature Protocols*, vol. 1, pp. 297–301, 2006.

[47] B. M. Okada, and L. R. Slevc, “Musical training: Contributions to executive function,” in *An Integrative Approach to Cognitive and Working Memory Training: Perspectives from Psychology, Neuroscience, and Human Development* (M. Bunting, J. Novick, M. Dougherty, and R. W. Engle Eds.), New York, NY: Oxford University Press, 2016.

[48] E. G. Schellenberg, and M. W. Weiss, “Music and cognitive abilities,” in *The psychology of music* (D. Deutsch, ed.), San Diego, CA, US: Elsevier Academic Press, pp. 499–550, 2013.

[49] F. Degé, C. Kubicek, and G. Schwarzer, “Associations between musical abilities and precursors of reading in preschool aged children,” *Frontiers in Psychology*, vol. 6., no. 1220, pp. doi: 10.3389/fpsyg.2015.01220