



Promises of Music in Education?

Mari Tervaniemi^{1,2,3*}, Sha Tao⁴ and Minna Huotilainen^{1,2}

¹ Cicero Learning, Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland, ² Cognitive Brain Research Unit, Department of Psychology and Logopedics, Faculty of Medicine, University of Helsinki, Helsinki, Finland, ³ Advanced Innovation Center for Future Education, Beijing Normal University, Beijing, China, ⁴ State Key Laboratory of Cognitive Neuroscience and Learning and IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing, China

Learning in school is intended to help students master academic skills such as reading, writing, and mathematics, as well as to acquire knowledge about different subjects such as history, geography, biology, and so on. However, in the future, successful learning will be largely manifested by students' global and transferable skills, such as analytical thinking, problem solving, collaboration, and social skills. Here we explore the promises of using music to support learning in the future. We review empirical evidence on the effects of music learning on neurocognitive development in children in formal and informal settings, in music interventions, and also in community settings. With this review, we wish to stimulate discussion about the roles that music could play in promoting learning in schools and elsewhere.

Keywords: music interventions, music education, child development, learning, transfer

OPEN ACCESS

Edited by:

Alessandro Antonietti,
Università Cattolica del Sacro Cuore,
Italy

Reviewed by:

Angela Jocelyn Fawcett,
Swansea University, United Kingdom
Natale Adolfo Stucchi,
Università degli studi di Milano
Bicocca, Italy

*Correspondence:

Mari Tervaniemi
mari.tervaniemi@helsinki.fi
orcid.org/0000-0002-9651-2929

Specialty section:

This article was submitted to
Educational Psychology,
a section of the journal
Frontiers in Education

Received: 03 May 2018

Accepted: 15 August 2018

Published: 04 October 2018

Citation:

Tervaniemi M, Tao S and
Huotilainen M (2018) Promises of
Music in Education?
Front. Educ. 3:74.
doi: 10.3389/feduc.2018.00074

INTRODUCTION

Globally, there is increasing demand for developing more efficient pedagogies and teaching tools to facilitate learning in school-aged children. Of particular interest is the need to support children in learning global and transferable skills, such as analytical thinking, problem solving, collaboration, and social skills.

In several countries, the most recent solution to this demand has been the use of digital learning environments and game-like environments (serious games or learning games). In parallel, several professional teachers have moved toward the use of arts as part of daily curriculum, also with the aim of teaching children academic skills. But what is known about art interventions and their potential to facilitate academic skill learning? In this paper, we review the existing literature particularly in the framework of music activities. This emphasis is justified by the variety and relatively long tradition of studies on music activities and their transfer effects. However, as will be seen, the research outcome does not offer an integrated view but, instead, invites us to continue systematic efforts to determine the promises of music in education.

Here, we first introduce the findings from those studies in which children have been involved in formal music training. This discussion is followed by findings from intervention studies in which short-term music training has been given to children as well as by findings about the effects of informal music activities. The review ends with a brief overview of ongoing projects in community settings. The literature is introduced in a very selective manner from the view point of education. This choice is intentional and based on the number of excellent recent reviews in

more general neurocognitive and psychological frameworks (White et al., 2013; Miendlarzewska and Trost, 2014; Moreno and Bidelman, 2014; Kraus and Nicol, 2017; Tervaniemi, 2017).

FORMAL MUSIC TRAINING

The research tradition investigating the impact of music training on brain functions was initiated in the 1990s when the first evidence about enlarged cortical areas in adult professional musicians compared to nonmusicians was presented (Elbert et al., 1995; Pantev et al., 1998). To indicate whether this neural benefit is caused by the music training or whether it is innate in individuals who later in life start training, this approach was followed by longitudinal studies in musically active children (Hyde et al., 2009; Putkinen et al., 2014a,b).

In these first longitudinal studies on the neural basis of music development, the participants were children with music hobbies (“music group”) and children without music training (“control group”). Hyde et al. investigated their 5–6-year-old children twice, before the training started and again after 15 months. They showed that the children in the music group had structural changes in their frontal, temporal, and parieto-occipital brain areas. Moreover, they also showed that these changes correlated significantly with improvements in auditory and motor tasks. Related neurocognitive development in the auditory memory was next investigated by using electroencephalogram (EEG) recordings in paradigms enabling one to determine how precisely the auditory brain areas react to changes in regular sound streams or in melodies (Putkinen et al., 2014a,b). Cortical brain responses to simple and more complex changes in musical and nonmusical sounds were recorded twice. These included both change-detection- and attention-allocation-related brain responses. In the first recordings at the age of 7 years, when most of the children in the music group just started their training, there were no group differences in the brain responses of interest. However, after two or more years, brain responses in the music group started to grow, while no such development in the brain responses of the control group was seen. Taken together, these findings indicate that the enhanced reactivity of the auditory system originally observed by Pantev in adult musicians is indeed caused by music training and is not innate and that *learning to play a musical instrument has an impact on the brain’s structure and function*.

However, in all the above-mentioned studies, the participants and their families chose the music activities. Thus, even if no brain differences were observable before the onset of the training, there might be other higher-order differences between the groups, e.g., in their family background and especially the socioeconomic status, personality (most importantly motivation), and cognitive abilities. Actually, Hyde et al. (2009) reported that the children in the music group had a higher socioeconomic status than the children who did not intend to start playing. This was statistically taken into account in the data analyses but, in the more general case, such bias should not be allowed to interfere in systematic studies on the effects of music.

The solution used in intervention studies, to be introduced next, is that the children are randomly allocated into groups with different interventions.

MUSIC INTERVENTIONS

Moreno et al. (2009, 2015) and Janus et al. (2016) used computerized learning environments to investigate the effects of music vs. foreign language training in childhood. In both domains, corresponding elements are taught: perception, reading, and production. These interventions were given as part of summer camp activities to large groups of children: First, to 36 4–6-year-old English-speaking children who received either French or music training for 20 days, 2 h a day (Moreno et al., 2015). Before the intervention, the children were tested with EEG, neurocognitive tests, and background questionnaires. They were divided into groups in a pseudorandom manner to ensure that there were no differences between groups on the neurocognitive test scores or in their background prior to the intervention. Immediately after the intervention, both groups showed enhanced brain reactions in the trained domain (music group in musical sounds; French group in French vowels) and, correspondingly, reduced reaction in the untrained domain. In the second study, using the same intensive learning environment for music vs. French, Janus et al. (2016) reported significant improvement of the executive functions of their 4–6-year-old children—again already in 20 days in both groups.

Furthermore, using pseudorandom group allocation, Moreno et al. (2011) compared the neurocognitive effects of computerized intervention for music and visual arts. Here, the intervention lasted for 20 days and the children were asked to practice twice a day for 1 h, each time. In the final analyses, there were 48 participants who were 4–6 years of age. It was found that the music intervention improved the verbal abilities of the children and that this was paralleled with the facilitation of the neural indices of executive functions. There were no identical improvements in children whose intervention was in the visual modality. This suggests that relatively short but very intensive music intervention can improve general cognitive functions necessary for all learning activities.

In a similar vein, linguistic functions have also been of interest recently. To extend the findings of Milovanov et al. (2008) about the association between music activities and foreign language learning, Ludke et al. (2014) conducted an intervention study in which adult participants were to learn foreign phrases by speaking, rhythmic speaking, or singing. The participants under the singing instruction outperformed the others particularly in production tests. Regarding the prerequisites for reading acquisition, such as spoken word encoding, Nan et al. (2018) have very recently shown (using a randomized assignment of the participants) that piano training in childhood was more effective than reading training as such. Thus, it seems that even short-term training in various music activities can result in transfer effects to linguistic and higher cognitive functions.

Unfortunately, these studies suffer from high dropout rates. For instance, in the study of Janus et al. (2016), 72 children

were recruited, of whom 57 were included in the analyses of their tests after the follow-up of 20 days. In Nan et al.'s study (2018), 120 children were recruited, of whom 74 were included in the analyses 6 months later (44 dropouts, 2 with EEG artifacts). Additionally, due to the high neural demands of the transfer skills to be established, it is not likely that an intervention of a couple of weeks/months would be imprinted at the neural level without a very intensive training protocol. This reasoning is supported by recent findings, indicating that only after 2 years of exposure to weekly music activities, brain responses are differentiated for musically active vs. inactive children (for review, see Kraus and Strait, 2015; see also Linnavalli et al., 2018 for behavioral findings).

INFORMAL MUSIC ACTIVITIES

Informal music activities are conducted in music play school or at home, without an intention of specific music learning, e.g., with regard to playing an instrument or singing. The neurocognitive effects related to these activities have been mainly investigated using correlational designs: parents were given a very detailed questionnaire assessing the role of informal music activities of their children (Putkinen et al., 2013). These activities included spontaneous singing, playing musical instruments without instruction, putting music on, asking parents to put music on, listening to parents singing or playing, dancing to music, and similar child-initiated activities without instruction. The frequency of these activities was then correlated with the brain reactions of the children when they heard distracting sounds (such as car or animal sounds) in the stream of standard regular musical sounds. It was found that the more the children were involved in music activities at home, the smaller were their brain responses to auditory distractors. This suggests that music activities may help children focus their attention on a given task and inhibit distractors. Corresponding evidence was obtained in deaf-born cochlear-implemented children in correlational (Torppa et al., 2014a) and in longitudinal designs across a 16-month period (Torppa et al., 2014b).

Music activities have been also shown to affect children's behavior. Even short sessions of joint singing and playing musical instruments seem to make children behave in a prosocial manner and increase their social skills. In 4-year-old children, a short session of joint music making was found to increase spontaneous cooperative and helpful behavior (Kirschner and Tomasello, 2010). Longer-term results have been observed as well. Preschool children's social skills and specifically social cooperation, social interaction, and social independence were found to increase when they participated in a music program compared to their peers who were on a waiting list (Ritblatt et al., 2013). Some children and adolescents may find the informal use of music and joint music making beneficial in dealing with their emotions and social pressures (Saarikallio et al., 2013). Even if this empirical evidence about the possibilities of music to promote social behavior is limited, in our view and together with anecdotal evidence and

experiences, it is promising enough to be used as a starting point for further research and development projects in school contexts, particularly when global and transferable skills are of interest.

STUDIES IN COMMUNITY SETTINGS

In everyday learning contexts, it is not feasible to plan using 2 h of a day for a computerized intervention program in addition to or instead of a regular school curriculum. Instead, interventions that last longer and are less intense are preferred for obvious practical reasons. As noted above, both formal and informal music activities may have positive carryover effects on children's neurocognitive development. In this framework, several projects have been established internationally to offer music activities either as in-school or extracurricular activities.

In the Netherlands, 147 school children were followed for 2.5 years while pursuing in-school art projects (Jaschke et al., 2018). They were randomized into four groups: two music intervention groups, one visual arts group, and passive control group. Children in the visual arts group outperformed on visuospatial memory tasks as compared to the other three groups. However, other outcome measures (inhibition, planning, and verbal intelligence) indicated significantly improved performance in the post-tests in the two music groups compared to the other groups. Additionally, a possible transfer effect from executive subfunctions to academic performance scores was found in music groups.

In the U.S., two large studies are currently ongoing to systematically follow the efficacy of such art intervention programs established in community settings for underprivileged children. The first results have been already released, showing that in two (but not in one) years, those auditory processes that underlie intact literacy skills are fine-tuned by music activities (Harmony project <https://www.harmony-project.org/>; see Kraus et al., 2014; Kraus and Strait, 2015). Music activities were found to improve children's hearing in noise as well (Slater et al., 2015). Tierney et al. (2015) showed in an earlier study that subcortical auditory processes are advanced by in-school music training in adolescence, indicating that neuroplasticity in the auditory modality is not limited to childhood. From an "Il Sistema"-based intervention (<http://sistema-toronto.ca/>), we now know that it also facilitates sound-related neural functions in 2 years from the project onset. Such facilitation is not observed after a sport-based intervention, or in control children (Habibi et al., 2016, 2017; for a review see Habibi et al., 2018).

These findings can be interpreted in the theoretical frameworks of Overy (2003), Tallal and Gaab (2006), and Goswami (2015) who proposed that paying attention to various sound features intrinsic to music (particularly rhythm, phoneme rise time, and duration) can be helpful for phonemic awareness to emerge that, in turn, is a requirement for literacy skills. However, it is noteworthy that we still lack direct evidence for music training enhancing literacy skills as such.

In parallel, three intervention studies, also in community settings, are currently in progress. The first of these was

established in Finnish Kindergartens in which weekly music play school and dance programs were integrated into the regular program of the children (Linnavalli et al., 2018). According to the results of this study, music (but not dance) activities improved the linguistic skills of the children in terms of vocabulary and phonemic processes—again only after 2 years but not after one (Linnavalli et al., 2018). The second intervention is in progress in an elementary school for 7–10-year-old children in Beijing: children receive extracurricular lessons in music or in foreign language two to three times a week for one academic year. The third intervention is ongoing in an elementary school in Finland: teachers were mentored to include movement- and music-related brief activities as part of their lessons, a couple of times a week. In all these three studies, interventions are preceded and followed by neurocognitive and EEG tests, together with questionnaires and, in the schools, also tests on academic achievement. Our aim is to determine whether such easy-to-implement interventions can facilitate the learning of academic skills as well as improve social cognition.

DISCUSSION AND CONCLUSIONS

As introduced above, music activities of several kinds can be evidenced in the brain dynamics and in larger-scale behavioral functions. However, admittedly, these findings need to be considered with care and new studies need to be conducted. Issues to be considered in the light of the current literature include possible biases in scientific publication practices, in media appearance, as well as in various aspects related to experimental designs.

In scientific journals, the highest priority is given to novel results that carry implications for both science and society. For journals, research papers on the power of music to remediate disorders, and particularly about the transfer effects of music learning are obviously very “catchy.” Papers on such topics are likely to attract the attention of editors as well as reviewers and, naturally, to receive a broad readership. However, replications of now-already-classic paradigms, as well as novel paradigms obtaining negative/null results about the positive effects of music, should also be given space in journals. This would give a broader picture to the scientific community about the impact of music (and other arts and hobbies) on typical and atypical development.

In media, the importance of always finding increasingly novel and “striking” findings is very high. Easy means to achieve success, health, and well-being are favored in the headlines. This trend is best illustrated by the (mis)interpretation of short-term increase of spatiotemporal reasoning abilities after music listening as a very broad and long-term benefit of music listening in any mental or cognitive domain, including intelligence (for original finding, see Rauscher et al., 1993; for an early example of a media headline, see <https://www.nytimes.com/1994/08/28/arts/classical-view-listening-to-prozac-er-mozart.html>). Indeed, as follow-up studies showed, music listening does not make us smarter—even though listening to music might improve task performance

by increasing the level of vigilance (e.g., see Schellenberg and Hallam, 2005). Therefore, close collaboration between scientists and science journalists is the key to decide what we can say to laypeople about study findings and their implications and to analyze how laypeople will interpret the findings.

From scientific and media viewpoints, when reporting a research outcome, clearly differentiating the results from their implications is important. Indeed, there are findings that are highly consistent at the neural level but less so when it comes to the behavioral level. In other words, sometimes the effects of music intervention or longer-term music expertise are most reliably seen as the sensitization of neural indices without parallel improvements in neuropsychological tests—or the other way around. This implies that our research paradigms need further tuning to probe the same or at least corresponding phenomena at the neural and behavioral levels of neurocognitive processes.

Last but definitely not least, we need to reconsider how to optimize experimental designs so that they meet the scientific criteria but, in parallel, reflect the real-life use and practices of music-making. How to balance between several music practices (singing, playing, dancing, listening, etc.) so that the outcome is enjoyable for the participants and teachers and, at the same time, also educational in a wider framework—even up to transfer effects (e.g., Miendlarzewska and Trost, 2014)? How to choose the most optimal design for grouping the participants into different activities? In this context, some scholars emphasize the need for randomized controlled trials, following the traditions of animal and clinical research (e.g., see Sala and Gobet, 2017). In this practice, as well as in pseudorandom group allocation, biases caused by preexisting differences in any perceptual, cognitive, or socioemotional cause can be ruled out. In parallel, when conducting long-term follow-up studies, the benefits of group allocation based on preference and motivation are obvious. As put by Habibi et al. (2017): “.., if children were not motivated and not emotionally engaged in the chosen activity, it is unlikely that they would continue participation over the long period necessary for a longitudinal investigation. In addition, assigning children to specifically not engage in an activity thought to be beneficial during critical times of development, and for long periods, would simply be unethical.” Importantly, there is the possibility to control for possible biases in nonrandomized group allocations by statistical means (e.g., educational level of the parents or any personality trait can be used as a covariate in the analyses as already mentioned when discussing Hyde et al., 2009 above). Based on this, we strongly promote the use of naturalistic real-life group allocations, without randomization. Using such a design, long-term follow-up studies can also be conducted with reasonably few dropout participants; in the study of Habibi et al., there were about the same number of dropout participants in 2 years than in Janus et al.’s (2016) study in 1 month.

To conclude, for children to learn global and transferable skills such as analytical thinking, problem solving, collaboration, and social skills, the affordances offered by music and other arts should be given key consideration. These arts offer a variety of

possibilities to children for learning during interaction. The arts offer challenges for motor skills and audiovisual integration and, in parallel, promote esthetic as well as intellectual processes. It is also noteworthy that even if, in most cases, art learning takes place without conscious effort, particularly in its informal and implicit forms, there are also moments in which self-discipline and self-monitoring are of importance. Thus, artistic activities also lay the groundwork for the development of executive functions.

When investigating the effectiveness of art-based interventions established in naturalistic settings such as schools, clubs, and homes, we necessarily need new methods and paradigms for research. Could we consider investigation of a small group of children at once? Could we conduct investigations in schools instead of laboratories? Could we follow-up children's learning online, during the learning process? Technology for such studies exists, but to use it calls for additional financial resources—for example to plan experiments and analyze data—as well as curiosity and a pioneering mind-set from academics.

REFERENCES

- Elbert, T., Pantev, C., Wienbruch, C., Rockstroh, B., and Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science* 270, 305–307. doi: 10.1126/science.270.5234.305
- Goswami, U. (2015). Sensory theories of developmental dyslexia: three challenges for research. *Nat. Rev. Neurosci.* 16, 43–54. doi: 10.1038/nrn3836
- Habibi, A., Cahn, B. R., Damasio, A., and Damasio, H. (2016). Neural correlates of accelerated auditory processing in children engaged in music training. *Dev. Cogn. Neurosci.* 21, 1–14. doi: 10.1016/j.dcn.2016.04.003
- Habibi, A., Damasio, A., Ilari, B., Elliott Sachs, M., and Damasio, H. (2018). Music training and child development: a review of recent findings from a longitudinal study. *Ann. N. Y. Acad. Sci.* 1423, 73–81. doi: 10.1111/nyas.13606
- Habibi, A., Damasio, A., Ilari, B., Veiga, R., Joshi, A. A., Leahy, R. M., et al. (2017). Childhood music training induces change in micro and macroscopic brain structure: results from a longitudinal study. *Cereb. Cortex* doi: 10.1093/cercor/bhx286. [Epub ahead of print].
- Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., et al. (2009). Musical training shapes structural brain development. *J. Neurosci.* 29, 3019–3025. doi: 10.1523/JNEUROSCI.5118-08.2009
- Janus, M., Lee, Y., Moreno, S., and Bialystok, E. (2016). Effects of short-term music and second-language training on executive control. *J. Exp. Child Psychol.* 144, 84–97. doi: 10.1016/j.jecp.2015.11.009
- Jaschke, A. C., Honing, H., and Scherder, E. J. A. (2018). Longitudinal analysis of music education on executive functions in primary school children. *Front. Neurosci.* 12:103. doi: 10.3389/fnins.2018.00103
- Kirschner, S., and Tomasello, M. (2010). Joint music making promotes prosocial behavior in 4-year-old children. *Evol. Hum. Behav.* 31, 354–364. doi: 10.1016/j.evolhumbehav.2010.04.004
- Kraus, N., and Nicol, T. (2017). The power of sound for brain health. *Nat. Hum. Behav.* 1, 700–702. doi: 10.1038/s41562-017-0201-7
- Kraus, N., Slater, J., Thompson, E. C., Hornickel, J., Strait, D. L., Nicol, T., et al. (2014). Music enrichment programs improve the neural encoding of speech in at-risk children. *J. Neurosci.* 34, 11913–11918. doi: 10.1523/JNEUROSCI.1881-14.2014
- Kraus, N., and Strait, D. L. (2015). Emergence of biological markers of musicianship with school-based music instruction. *Ann. N. Y. Acad. Sci.* 1337, 163–169. doi: 10.1111/nyas.12631
- Linnavalli, T., Putkinen, V., Lipsanen, V., Huotilainen, M., and Tervaniemi, M. (2018). Music playschool enhances children's linguistic skills. *Sci. Rep.* 8:8767. doi: 10.1038/s41598-018-27126-5

AUTHOR CONTRIBUTIONS

MT drafted the manuscript. MH and ST commented on the manuscript. All authors approved the final submission.

ACKNOWLEDGMENTS

MT was supported by the open fund project of the State Key Laboratory of Cognitive Neuroscience and Learning as well as by the Future School 2030 initiative of the Advanced Innovation Center for Future Education, Beijing Normal University. She also received support from the Finnish Cultural Foundation, Helsinki, Finland, for her project on music and dance to promote learning. Additionally, she collaborates with the ARTSEQUAL consortium supported by the Strategic Research Council, Academy of Finland. ST was supported by National Science Foundation grants (31521063, 71641015). We thank Cuicui Wang, Qinfang Xu, and Shuting Li for their help in literature search and Dr. Ben Cowley for proofreading the final manuscript.

- Ludke, K. M., Ferreira, F., and Overy, K. (2014). Singing can facilitate foreign language learning. *Mem. Cogn.* 42, 41–52. doi: 10.3758/s13421-013-0342-5
- Miendlarzewska, E. A., and Trost, W. J. (2014). How musical training affects cognitive development: rhythm, reward, and other modulating variables. *Front. Neurosci.* 7:279. doi: 10.3389/fnins.2013.00279
- Milovanov, R. R., Huotilainen, M., Välimäki, V., Esquef, P. A. A., and Tervaniemi, M. (2008). Musical aptitude and second language pronunciation skills in school-aged children: neural and behavioral evidence. *Brain Res.* 1194, 81–89. doi: 10.1016/j.brainres.2007.11.042
- Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., and Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychol. Sci.* 22, 1425–1433. doi: 10.1177/0956797611416999
- Moreno, S., and Bidelman, G. M. (2014). Examining neural plasticity and cognitive benefit through the unique lens of musical training. *Hear. Res.* 308, 84–97. doi: 10.1016/j.heares.2013.09.012
- Moreno, S., Lee, Y., Janus, M., and Bialystok, E. (2015). Short-term second language and music training induces lasting functional brain changes in early childhood. *Child Dev.* 86, 394–406. doi: 10.1111/cdev.12297
- Moreno, S., Marques, C., Santos, A., Santos, M., and Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: more evidence for brain plasticity. *Cereb. Cortex* 19, 712–723. doi: 10.1093/cercor/bhn120
- Nan, Y., Liu, L., Geiser, E., Shu, H., Gong, C. C., Dong, Q., et al. (2018). Piano training enhances the neural processing of pitch and improves speech perception in Mandarin-speaking children. *Proc. Natl. Acad. Sci. U.S.A.* 115, E6630–E6639. doi: 10.1073/pnas.1808412115
- Overy, K. (2003). Dyslexia and music. From timing deficits to musical intervention. *Ann. N. Y. Acad. Sci.* 999, 497–505. doi: 10.1196/annals.1284.060
- Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L. E., and Hoke, M. (1998). Increased auditory cortical representation in musicians. *Nature* 392, 811–814. doi: 10.1038/33918
- Putkinen, V., Saarikivi, K., and Tervaniemi, M. (2013). Do informal musical activities shape auditory skill development in preschool-age children? *Front. Psychol.* 4:572. doi: 10.3389/fpsyg.2013.00572
- Putkinen, V., Tervaniemi, M., Saarikivi, K., de Vent, N., and Huotilainen, M. (2014a). Investigating the effects of musical training on functional brain development with a novel Melodic MMN paradigm. *Neurobiol. Learn. Mem.* 110, 8–15. doi: 10.1016/j.nlm.2014.01.007
- Putkinen, V., Tervaniemi, M., Saarikivi, K., Ojala, P., and Huotilainen, M. (2014b). Enhanced development of auditory change detection in musically trained school-aged children: a longitudinal event-related potential study. *Dev. Sci.* 17, 282–297. doi: 10.1111/desc.12109

- Rauscher, F. H., Shaw, G. L., and Ky, K. N. (1993). Music and spatial task performance. *Nature* 365, 611. doi: 10.1038/365611a0
- Ritblatt, S., Longstreth, S., Hokoda, A., Cannon, B. N., and Weston, J. (2013). Can music enhance school-readiness socioemotional skills? *J. Res. Child. Educ.* 27, 257–266. doi: 10.1080/02568543.2013.796333
- Saarikallio, S., Nieminen, S., and Brattico, E. (2013). Affective reactions to musical stimuli reflect emotional use of music in everyday life. *Musicae Sci.* 17, 27–39. doi: 10.1177/1029864912462381
- Sala, G., and Gobet, F. (2017). When the music's over. Does music skill transfer to children's and young adolescents' cognitive and academic skills? A meta-analysis. *Educ. Res. Rev.* 20, 55–67. doi: 10.1016/j.edurev.2016.11.005
- Schellenberg, E. G., and Hallam, S. (2005). Music listening and cognitive abilities in 10- and 11-year-olds: the blur effect. *Ann. N. Y. Acad. Sci.* 1060, 202–209. doi: 10.1196/annals.1360.013
- Slater, J., Skoe, E., Strait, D., O'Connell, S., Thompson, E. C., and Kraus, N. (2015). Music training improves speech-in-noise perception: longitudinal evidence from a community-based music program. *Behav. Brain Res.* 291, 244–252. doi: 10.1016/j.bbr.2015.05.026
- Tallal, P., and Gaab, N. (2006). Dynamic auditory processing, musical experience and language development. *Trends Neurosci.* 29, 382–390. doi: 10.1016/j.tins.2006.06.003
- Tervaniemi, M. (2017). Music in learning and re-learning – The lifespan approach. *Psychomusicology* 27, 223–226. doi: 10.1037/pmu0000185
- Tierney, A. T., Krizman, J., and Kraus, N. (2015). Music training alters the course of adolescent auditory development. *Proc. Natl. Acad. Sci. U.S.A.* 112, 10062–10067. doi: 10.1073/pnas.1505114112
- Torppa, R., Faulkner, A., Huottilainen, M., Järvikivi, J., Lipsanen, J., Laasonen, M., et al. (2014a). The perception of prosody and associated auditory cues in early-implanted children: the role of auditory working memory and musical activities. *Int. J. Audiol.* 53, 182–191. doi: 10.3109/14992027.2013.872302
- Torppa, R., Huottilainen, M., Leminen, M., Lipsanen, J., and Tervaniemi, M. (2014b). Interplay between singing and cortical processing of music: a longitudinal study in children with cochlear implants. *Front. Psychol.* 5:1389. doi: 10.3389/fpsyg.2014.01389
- White, E. J., Hutka, S. A., Williams, L. J., and Moreno, S. (2013). Learning, neural plasticity and sensitive periods: implications for language acquisition, music training and transfer across the lifespan. *Front. Syst. Neurosci.* 7:90. doi: 10.3389/fnsys.2013.00090

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2018 Tervaniemi, Tao and Huottilainen. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.