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REVIEW ARTICLE

Implications of musical practice in central auditory processing: a systematic review

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Abstract
Introduction: Recent studies have shown that musical practice and training are effective and have the potential to assist in the acquisition and improvement of auditory skills.
Objective: To verify the scientific evidence on the implications of musical practice in central auditory processing.
Methods: A systematic review was carried out in accordance with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), using the Medline (Pubmed), LILACS, SciELO, BIREME, Scopus and Web of Science databases. The search period for the articles covered the last 5 years (2015–2020), without restriction of language and location. The quality of the articles was assessed, and the review included articles with a minimum score of 6 in a modified literature quality scale.
Results: Initially, 1362 publications were found, of which 1338 were excluded after the title screening, 15 were excluded due to the abstract, with nine articles being analyzed in full and four of them excluded after the analysis, as they did not answer the guiding question proposed for this research. Five articles that met the proposed inclusion criteria were admitted for this research. It was found that in adults, musical ability is associated with better performance of several auditory processing skills, as well as the fact that musical training in children promoted an accelerated maturity of auditory processing and exposure to music facilitated the learning of auditory information in newborns.
Conclusion: Considering the scientific evidence, it was found that the musical experience can improve specific skills of the central auditory processing, regardless of age, optimizing children's linguistic development.

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Introduction

According to Brescia,[1] the first civilizations used music in all their rituals, such as during birth and death. Music stimulates people's physical, emotional, cognitive and social status. Imaging exams demonstrate activity in parts of the brain, in areas associated with hearing and emotions, when they come into contact with music,[2] and when a musical instrument is played, neural connections are created, connecting the two brain hemispheres, which begin to work together.[3]

Central auditory processing (CAP) refers to a series of processes involved in the detection of and reaction to the sounds received and predominantly involves the structures of the central nervous system (CNS);[4] however, for a correct decoding to occur, it is necessary that the auditory skills be complete and effective.[5] It is observed that alterations in this system can lead to difficulties in learning, understanding and language delay.[6]

The CAP includes sound recognition and localization skills, sharing of attention between two stimuli, selecting an auditory stimulus in the presence of background noise, differentiating the variation of frequency, intensity and duration of the sound, in addition to perceiving differences and similarities between verbal sounds,[7] and musical practice is considered to favorably stimulate these skills,[8] becoming an ally in the treatment and prevention of some disorders.[9,10]

The auditory processing integrity is a prerequisite for the development of language skills. It is reported that the musical experience positively contributes to the global development of children, as well as in the metalinguistic skills.[10,11] The musical experience that can promote improvement in the auditory processing and phonological awareness skills in children of 5 years stands out.[12]

Research suggests that brain plasticity is induced by musical practice and, therefore, a functional and structural difference in the musicians' brain auditory areas when compared to that of non-musicians,[13–16] which may indicate a faster processing of auditory stimuli, represented, for instance, by the decreased latency and greater P3 amplitude in that population.[17]

Recent studies have shown that musical practice and training improve the auditory processing skills,[7,18] which have shown to be effective and have potential to be used in children, aiming to assist in the acquisition of auditory skills, as well as to improve them.[7]

Based on the abovementioned facts, the present study has as its main and guiding objective the verification of the scientific evidence on the implications of musical practice in central auditory processing, aiming to answer the following research question: What are the implications of musical practice in central auditory processing?

Methods

Protocol and registration

This systematic review was carried out in accordance with PRISMA (*Preferred Reporting Items for Systematic reviews and Meta-Analyses*) recommendations.[19]

Table 1 Description of PICOS components.

Acronym	Definition
P	Patients
I	Music
C	Musical Practice
O	CAP
	Descriptive study
	Cross-sectional study
	Observational study
S	Case reports
	Case-control studies
	Controlled clinical trials
	Cohort studies

Source: Developed by the authors.
CAP, Central Auditory Processing.

The search for scientific articles were carried out by two independent researchers in the MEDLINE (Pubmed), LILACS, SciELO, Scopus, Web of Science and BIREME electronic databases, without restriction of language, period and location. The research was structured and organized according to the PICOS model, which is an acronym for Target Population, Intervention, Comparison, Outcomes" and Study type". The population of interest or health problem (P) corresponds to patients; intervention (I) refers to music; comparison (C) corresponds to exposure to musical practice; outcomes (O) refers to the CAP; and the types of studies (S) accepted were descriptive, cross-sectional, observational studies, case reports, case-control studies, controlled clinical trials and cohort studies (Table 1).

Search strategy

The descriptors were selected from the Health Sciences Descriptors (DeCS) dictionary and Medical Subject Heading Terms (MeSH), considering their wide use by the scientific community for the indexing of articles in the PubMed database. Considering the search for descriptors, the adequacy for the other databases used in the search was carried out. Initially, the following combination of descriptors was proposed for the searches: (music) and (auditory processing) and (central nervous system). The search was concentrated in July 2020.

Eligibility criteria

The designs of the studies initially accepted were descriptive, cross-sectional, observational, case-control, cohort studies, case reports and controlled clinical trials. The studies were included without restriction of language, period and location. Table 2 represents the inclusion and exclusion criteria developed in this research. The studies scored higher than 6 according to the modified protocol by Pithon et al.[20] to have their quality assessed.

Risk of bias

The quality of the methods used in the included studies was independently assessed by the reviewers (PH, CHB and LFG),

Table 2 Summary of inclusion/exclusion criteria.

Inclusion criteria	
Design	Case reports Case-control studies Controlled clinical trials Cohort studies Screening studies Observational studies
Location	Without restriction
Language	Without restriction
Period	January 2015 to June 2020
Exclusion Criteria	
Design	Literature reviews Systematic reviews Meta-analyses Case studies Preference studies
Studies	Unclear studies Poorly described or inadequate
Type of publication	Abstract only

Source: Developed by the authors.

according to the PRISMA recommendation.[19] The assessment prioritized the clear description of information. At this point, the review was carried out blindly, after masking the names of the authors and journals, avoiding any potential bias and conflicts of interest.

Exclusion criteria

Studies published as Letters to the Editor, Guidelines, Literature Reviews, Narrative Reviews, Systematic Reviews, Meta-analyses and Abstracts were excluded. Studies with missing information or which were unclear about it, or were not available as full-text, were also excluded as shown in Table 2.

Data analysis

The extraction of data for the study eligibility process was performed using a specific form for the systematic review prepared by two researchers using the Excel® program, in which the extracted data were initially added by one of the researchers and then checked by another researcher. First, they were selected according to the title. The abstracts were then analyzed and only those that were potentially eligible were selected. Based on the abstracts, the articles were selected for full reading, and the ones that met all predetermined criteria were accepted. In case of disagreement between the evaluators, a third one made the decision regarding the eligibility of that specific study.

Study selection procedure

Initially, the eligibility reviewers (CHB and LFG) were calibrated to perform the systematic review by FSAP, KMP and PH. After calibration and clarification of doubts, the titles and abstracts were independently assessed by two eligibility reviewers (CHB and LFG), who were not blinded to the names of the authors and the journals. The ones that showed a title within the scope, but for which abstracts were not available, were also obtained and analyzed in full.

Subsequently, the preliminary eligible studies had the full text obtained and assessed. In specific cases, when the study with potential for eligibility showed incomplete data, the authors were contacted by email to obtain more information. In the absence of agreement between the reviewers, a third party (PH) was called in for the final decision.

Collected data

After the screening, the texts of the selected articles were reviewed and extracted in a standardized manner by two authors (CHB and LFG) under the supervision of KMP, FSAP and PH, identifying the year of publication, place of research, language of publication, type of study, study sample, method, result and conclusion.

Clinical outcome

The clinical result of interest was to analyze the effect of music on auditory processing. The studies that did not use the musical effect approach in auditory processing were not included in the literature review sample.

Results

Based on the chosen descriptors, the databases were consulted and the results, available in Table 3, were obtained.

Initially, 1362 publications were found, of which 1338 were excluded after the screening of the title and 15 were excluded after the abstract was read, with nine articles being analyzed in full and four of them excluded after analysis, as they did not meet the inclusion criteria proposed for this research. Thus, five publications were included in this study (Fig. 1).

The designs of the included studies comprise the cross-sectional and longitudinal types, all with a score of 11 in the modified protocol of Pithon et al.,[20] which rigorously evaluates the quality of publications. The data extracted from the studies were descriptively and comparatively assessed.

Regarding the description of the results of the eligible articles in this study, the information was presented in a detailed format, as the potentials analyzed in the evaluations, the stimuli used and other information, as shown in Table 4.

In three included studies, the sample consisted of 20 adult individuals, divided into groups of musicians and non-musicians.[21–23] Regarding the age of the participants, in one of them age ranged from 22 to 59 years;[23] in two others, the mean age of musicians was 23 years old (SD = 2)[21] and 42.2 years old (SD = 16.04)[22] and among the non-musicians, it was 24 years old (SD = 2)[21] and 38.4 years (SD = 12.03).[22] The other two studies selected in this research were carried out with newborns (n = 21)[24] and with children aged 6–7 years (n = 7).[25]

Table 3 Classification of references obtained in Pubmed, SciELO, LILACS, Web of Science and Scopus databases.

Descriptors	N.	Excluded references	Reason	Selected	Database
(music) and (auditory processing) and (central nervous system)	293	290	Excluded by the title (282); excluded by the abstract (8)	3	Pubmed
(music) and (auditory processing) and (central nervous system)	–	–	–	0	LILACS
(music) and (auditory processing) and (central nervous system)	1	1	Excluded by the title (1)	0	SciELO
(music) and (auditory processing) and (central nervous system)	443	442	Excluded by the title (440); excluded by the abstract (2);	1	Web of Science
(music) and (auditory processing) and (central nervous system)	10	10	Did not meet the inclusion criteria (4); excluded by the title (5)	1	BIREME
(music) and (auditory processing) and (central nervous system)	615	615	Excluded by the abstract (5); excluded by the title (610)	0	Scopus
Total	1362	1357		5	

Source: Developed by the authors.

While studies with adults [21–23] evaluated the central auditory nervous system function of musicians and non-musicians, considering that musicians should already have a history of prolonged exposure to music, studies with children[25] and newborns[24] exposed these subjects to different sound stimuli, aiming to assess the effects of this exposure on the auditory pathway.

The mean time of exposure to musical practice in one of the studies carried out with adults was 14 years (SD = 2 years);[21] in another, this time ranged from 16 to 54 years, with 80% of the musicians having 40 years or more of exposure, all for at least 15 h a week.[23] In one of them, the time of exposure of the musicians was not provided, although they took this factor into account when quantifying the musical background and experience through a questionnaire (Iowa Musical Background Questionnaire - IMBQ).[22]

In the study by Habibi et al. [25] the children in the group exposed to musical training (n = 13), for a period of 6–7 h a week for two years, were compared with two other groups of children with the same socioeconomic background, one of which was involved in sports training (n = 11) and another without any involvement in systematic training (n = 13).

In the study by Suppanen et al.,[24] newborns were submitted to the Finnish version of a well-known lullaby, recorded by a native speaker of the language, under three different conditions, using two different verses in each condition: a version read as a lullaby, spoken metrically; a version sung with a certain melody; and, a version read as common speech. Under the three conditions, the potentials related to the newborns' hearing events were recorded. Then, the learning effect was investigated, introducing sporadic changes in vowel, word, pitch and intensity in the excerpts of speech and recording the neural responses to them.

The methodologies used by the authors to assess the function of the central auditory pathway were varied, including behavioral/psychoacoustic [22,23,25] and electrophysiological assessments.[21,23,25] Among the behavioral tests used were speech-in-noise tests, pitch discrimination,[22,23] timbre recognition (closed set task),[22] tone/rhythm discrimination,[25] in addition to the Gaps-In-Noise (GIN) and Sinusoidal Amplitude Modulation (SAM) tests.[23] The electrophysiological examinations, used in the five selected studies,[21–25] are related to the recording of event-related potentials (ERP) or cognitive potentials, which are widely used to assess the development of the central auditory system and allow the identification of stages of the sensory and cognitive process in response to auditory stimuli. The analyzed potentials, as well as the stimuli used, are shown in Table 4.

As for the results obtained from the studies developed with adults, there was a significant correlation between musical ability and P3 latencies, with the latencies obtained in musicians being lower than those recorded in non-musicians,[21] in addition to higher amplitudes of cortical responses.[22] Musicians were shown to be able to detect

Table 4 Results of the selected studies.

Author/ Year/ Place of study/ Type of study	Objective	Analyzed potential(s)	Used stimulus	Results	Conclusion
Fabhauer et al.,[21] 2015 Cross-Sectional Germany	To verify the association between musical ability and short-term cognitive processing, measured by the event-related potentials.	P1, N1, P2, N2, P3	Not specified	The most important finding was that there is a significant linear correlation between musical ability as measured by these tests and the P3 latencies of the potentials related to auditory and visual events. Moreover, musicians showed shorter latencies of event-related potentials than non-musicians.	Musical ability, measured by neuropsychological tests, is associated with improved short-term cognitive processing, both in the auditory domain and, surprisingly, also in the visual domain..
Brown et al.,[22] 2017 Cross-sectional United States	To determine whether the acoustic change complex (ACC) is sensitive enough to reflect the differences in spectral processing exhibited by musicians and non-musicians.	ACC	Speech in noise; sequence of four notes from six musical instruments; series of three simulated clarinet notes, digitally generated; ripple noise.	Musicians were capable of detecting minor changes in pitch than non-musicians. They were also capable of detecting a change in the position of the peaks and valleys in a ripple noise stimulus at higher ripple densities than non-musicians. The ACC responses recorded by musicians were greater than those recorded by non-musicians when the amplitude of the ACC response was normalized to the amplitude of the initial response in each pair of stimuli. The visual detection thresholds derived from the evoked potential data were better for musicians than for non-musicians, regardless of whether the task was the discrimination of musical tuning or detection of a change in the frequency spectrum of ripple noise stimuli. Behavioral discrimination measures were generally more sensitive than electrophysiological measures. However, the two metrics were correlated.	Musicians are more capable of discriminating spectrally complex acoustic signals than non-musicians. These differences are evident not only in the perceptual / behavioral tests, but also in the electrophysiological measurements of the neural response at the level of the auditory cortex. Although these results are based on observations made by listeners with normal hearing, they suggest that ACC may provide a non-behavioral method of assessing hearing discrimination and, as a result, may be useful in future studies that explore the effectiveness of participating in a musical environment, auditory training program, perhaps aimed at pediatric or hearing impaired listeners.

Table 4 (*Continued*)

Author/ Year/ Place of study/ Type of study	Objective	Analyzed potential(s)	Used stimulus	Results	Conclusion
Meha-Bettison et al.,[23] 2018 Cross-sectional United States	To investigate whether professional musicians outperformed non-musicians in auditory processing and speech in-noise perception	P1, N1 e P2	/ da / syllable	Musicians significantly outperformed non-musicians in the task of frequency discrimination and speech perception in noise (target voice and competitive voice equal to 0°). The N1 amplitude of the musicians showed no difference between the conditions of 5 dB and 0 dB, while the non-musicians showed a significantly lower N1 amplitude at 0 dB when compared to 5 dB. The time-frequency analysis indicated that the musicians had significantly higher alpha power desynchronization at 0 dB, indicating attention involvement.	Using behavioral and electrophysiological data, the results provide converging evidence that shows better speech recognition in noise by musicians.
Suppanen et al.,[24] 2019 Cross-sectional Finland	To verify whether music and rhythm can facilitate the learning of hearing information in newborns.	Not specified	Finnish version of a well-known lullaby song in three different conditions (lullaby song, music, speech)	Statistically significant brain responses were found in newborns when changes in syllables and words were presented in the lullaby song, but changes included in music and speech did not cause different cortical responses. The rhythmic structure of children's rhymes can facilitate the learning of newborns regarding auditory information.	Children's rhymes can facilitate newborns' learning through hearing information and, therefore, can be beneficial for language development.
Habibi et al.,[25] 2016 Longitudinal United States	To investigate the effects of a musical training program on children's hearing development, during 2 years, from 6 to 7 years old.	P1, N1, P2, N2, P3	Pure tone, piano and violin, combined in fundamental frequency with musical tones.	Before participating, the children who started musical training did not differ from those in the control groups regarding cognitive, motor, musical or brain measures. After 2 years, it was observed that the children in the musical group showed an improved ability to detect changes in the tonal environment and an accelerated maturity of the auditory processing, measured by the cortical auditory evoked potentials.	Musical training can result in specific brain changes in stimuli in schoolchildren.

Source: Fabhauer et al., 2015; Brown et al., 2017; Habibi et al., 2016; Meha-Bettison et al., 2018; Suppanen et al., 2019.
ACC, Acoustic Change Complex.

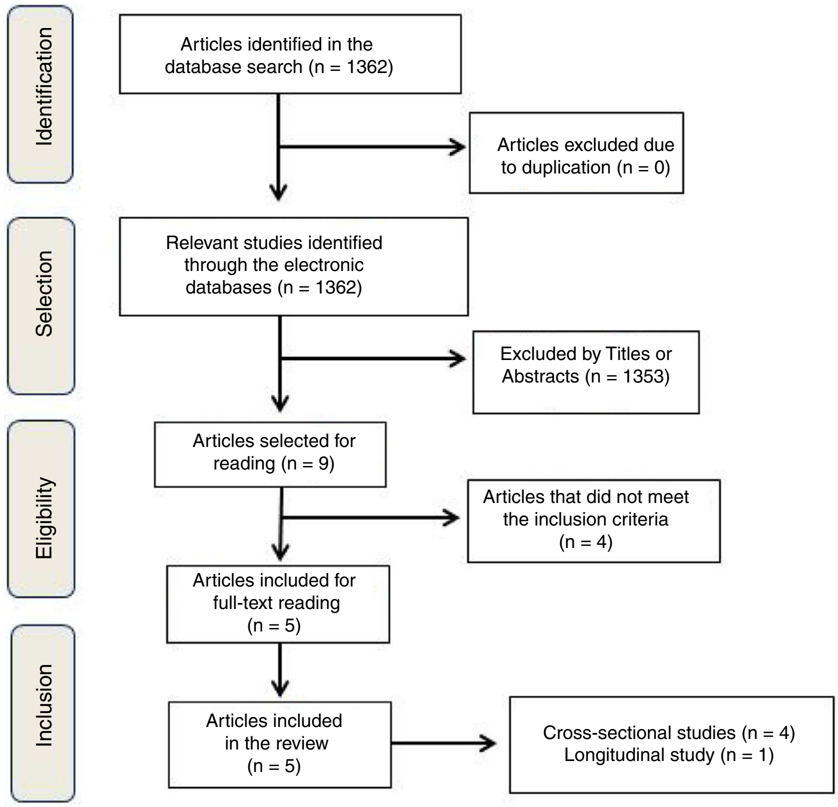

Figure 1 Flowchart of the article search and analysis process.

Source: Developed by the authors.

minor changes in pitch when compared to non-musicians.[22] Moreover, musicians were shown to have a better capacity to discriminate spectrally complex acoustic signals than non-musicians.[22] One of the studies also found that musicians showed better speech recognition in noise (equal target voice and competitive voice, applied at 0°), in addition to significantly outperforming non-musicians in the frequency discrimination task.[23]

The study carried out with children found that musical training, for a period of two years, may result in specific brain alterations, positively impacting the development of auditory skills, since the results show an improved capacity to detect changes in the tonal environment and accelerated maturity of the auditory processing of children submitted to musical training.[25]

As for the effects of music on newborns exposed to a well-known lullaby song in three different conditions (metrically spoken, sung with melody, and read as a speech), it was observed that the rhythmic structure of the lullaby song facilitated the learning of newborns with auditory information and, therefore, it can be beneficial for language development. It is worth mentioning that this effect was not observed with the other presented song.[24]

Discussion

The studies admitted in this systematic review agree regarding the effects of music or musical training, inferring that they improve auditory processing skills, in addition to causing cortical changes, which favor the learning and development of language in children and newborns, corroborating what was found in other publications.[7,12,26,27]

The literature points out that musical practice positively influences the CAP skills [9,18] and may be considered a tool to improve these skills, becoming a protective factor in relation to developmental disorders, especially those related to speech and language development.[9]

The study samples admitted to this systematic review consisted of adults, children aged 6–7 years and neonates, as the age range did not constitute an exclusion criterion. Other studies carried out to verify the effects of music, as well as musical training on populations of adults[17,28–33] and children[7,12,26,27,34–36] have been evidenced in the literature, and, overall, studies with children carry out the exposure to music/musical training during the study period, while studies with adults evaluate the effects of music that have been present in the subjects' daily lives for many years.

The literature on the effects of music, as well as musical training on the auditory processing of adults, is broad, showing a superiority in temporal ordering skills, [29] speech recognition in noise [28] and temporal resolution,[31] when compared to the performance of non-musicians, in addition to the fact that musicians show superiority in standardized subtests of visual, phonological and executive memory.[17] A study developed with 30 popular band singers compared their performance in auditory skills of temporal resolution and ordering between individuals who sing and play musical instrument(s) (n = 15) with the performance of those who only sing (n = 15) and verified that popular singers who play musical instruments have a better performance in those skills.[33]

Another study, carried out with 43 adults aged between 18 and 38 years, divided into three groups, one of which consisted of bilingual non-musician adults (n = 15), the other by monolingual English-speaking musicians (n = 13) and the control group, consisting of monolingual English speakers (n = 15), showed that bilingualism and musical training have differential effects on brain networks.[30]

When evaluating the P300 latency and amplitude in musicians (n = 30; between 20 and 53 years old) and non-musicians (n = 25; between 18 and 30 years old), in the absence and presence of contralateral noise, researchers found a greater inhibitory effect on musicians compared to non-musicians, showing that the central auditory nervous system of musicians has characteristic peculiarities due to the musical practice to which they are constantly exposed.[32] This potential was also assessed in a study developed with 32 university students aged between 18 and 24 years, divided into musicians and non-musicians, in which musicians should have been practicing a musical instrument for a long period (between 9 and 16 years), with the beginning of the practice occurring initially in childhood (between 5 and 10 years). The musicians demonstrated a faster update of working memory (lower latency P300) in the visual and auditory domains and allocated more neural resources to auditory stimuli (higher amplitude P300), demonstrating that long-term musical training is related to improvements in memory, both auditory and visual.[17]

In line with that observed in the adult population, as well as with the findings of the study carried out with children aged 6–7 years old included in this research,[25] the result of another study carried out with children aged 5 years showed that the musical experience promoted the improvement of auditory and metalinguistic skills,[12] and there is evidence that musical training positively influences reading skills and speech perception in noise, in addition to causing faster neural responses.[26]

Other results show positive effects of music on the transfer between cognitive domains in the pediatric population,[34,37] since musical training increases the sensitivity to a specific basic acoustic parameter, the tuning, which is equally important for the prosody of music and speech, improving children's ability to detect changes in tuning not only in music, but also in language.[37] When comparing the performance of 5-year-old children with and without musical practice, it is noteworthy that musical practice had a positive influence on the auditory skills of temporal ordering, sound localization and musical appreciation.[9]

There is longitudinal evidence that children's speech perception in noise improves after group musical training for a period of 2 years.[27] However, researchers found that 6 months of musical training were already sufficient to significantly improve behavior and influence the development of neural processes in 8-year-old children, strengthening theories about brain plasticity by showing that relatively short periods of training have strong consequences on the functional organization of children's brains.[34]

The lasting benefit of musical training was evidenced in a study carried out with children aged between 4 and 6 years, in which it was also possible to verify that new brain hemisphere changes appeared one year after the training.[36] Therefore, musical education plays an important role in child development, and musical training is also capable of shaping essential skills in the social and academic development.[25]

The evidence found in the study carried out with newborns infer that the simultaneous occurrence of exaggerated prosodic cues and items to be learned seems to help newborns to process language input, corroborating what was found in previous studies.[38,39] For Schon and Tillmann,[40] the rhyme in children's songs are natural auditory stimuli for newborns, improving phonological processing. The absence of learning evidence in neonates against a song presented as a certain melody, which is not a lullaby, may be due to the fact that the melody does not include sufficient variation in tuning or due to the challenging situation imposed by the simultaneous learning of the melody and phonetic content and not just the phonetic content.[24]

Although none of the studies selected for this research were carried out with the elderly population, there have been reports in the literature about the benefits of musical training in the auditory processing skills of non-hearing aid [41] and hearing aid elderly users.[42–44] A study developed with elderly people randomly assigned to learn how to play the piano (music), learn to play a video game (video) or to be used as a control (non-contact) found that after 6 months, the group that learned how to play the piano improved their ability to understand words presented in the presence of background noise, while the other two groups did not. It is important to observe that these findings suggest that musical training can be used as basis for the development of hearing rehabilitation programs for the elderly.[41]

Another important effect of music was found in a study that assessed the skills of auditory processing throughout life in musicians (n = 74) and non-musicians (n = 89), aged between 18 and 91 years old, and demonstrated that musicians experience less age-related decline in auditory tasks, such as gap detection and speech understanding in noise.[45] The differences between musicians and non-musicians in relation to behavioral and electrophysiological measures increase the expanding literature on experience-dependent plasticity in musicians.[23]

Studies indicate that there are structural differences between the brains of musicians and non-musicians, among which are the larger volume of the auditory cortex, greater concentration of gray matter in the motor cortex, and larger anterior corpus callosum. Studies involving neuroplasticity indicate a correlation between time of musical study and structural differences. Additionally, it is possible that there is a critical period related to these changes, indicating a possible correlation between the age at which music started being studied and structural brain changes.[46,47]

Seeking to understand the correlation between musical study and an increase in the corpus callosum, a research was carried out with children from 5 to 7 years old, who were divided into three groups, one group who had weekly practice of musical instrument from 1 to 2 h, one group who had weekly practice from 2 to 5 h and a control group that did not have music lessons. At the beginning of the study, there were no differences between the volumes of the subjects' corpus callosum. After 29 weeks of practice, there was a significant difference between the size of the corpus callosum in the children from the three groups, with a greater increase in the corpus callosum being observed in children with a longer time of exposure to musical practice.[48]

Another similar study carried out with 31 children divided into two groups, one of which (n = 15) had keyboard lessons for 15 months and the control group, which did not receive instrumental musical training, but only participated in weekly group music classes at school, found differences in regions such as the right precentral gyrus (motor area related to hand movement), corpus callosum and Heschl gyrus (primary auditory area),[49] findings that indicate a strong possibility of music-induced brain plasticity.

Structural brain alterations after musical training in early childhood, for a short period of time (15 months), were correlated with improved motor and auditory skills. These findings shed light on brain plasticity and suggest that structural brain differences evidenced in adult specialists are likely due to training-induced brain plasticity.[49] Putkinen et al.[35] upon finding an increase in the amplitudes of mismatch negativity (MMN) and P3a with the increase in age in musically trained children, with these increases not being evident in the initial stages of training, suggested that the superior neural auditory discrimination in adult musicians is due to training and not to pre-existing differences between musicians and non-musicians.

Regarding the procedures used to assess auditory processing in the studies chosen for this research, it was found that two of them used only electrophysiological assessment (ERP), [21,24] while the other three used behavioral procedures associated with electrophysiological assessment.[22,23,25] Therefore, ERPs were assessed in all studies, which constitute a valuable tool for the study of the neuronal activity generated during new information processing.[50]

Corroborating these findings, several studies that investigated the effects of music and musical training, found in the literature, also used electrophysiological procedures alone, by recording and analyzing event-related potentials,[30,32,35,36] while other studies used behavioral assessment associated with electrophysiological evaluation.[17,37,41] However, it was possible to verify that many studies were developed using only behavioral methods,[9,12,27–29,31,33] which were shown to be effective and represent the positive effects of music on the participants' auditory skills. Although the stimuli used to evoke the ERP were different, all of them were able to demonstrate the superiority of the musicians regarding their auditory skills.

The mean time of exposure to music in the studies selected for this systematic review varied considerably and none of them aimed to compare the performance in auditory processing skills according to the time of exposure; however, there is an agreement in the literature that points out that the longer the time of exposure, the more evident are the improvements in auditory processing skills.[7,17,18] However, there is evidence that shows that relatively short periods of musical training have strong effects on the brain functional organization in the child population, consolidating theories about brain plasticity.[34]

Conclusion

Considering the scientific evidence, it was found that the musical experience can improve specific skills of the central auditory processing, regardless of age, optimizing children's linguistic development. Moreover, individuals exposed to musical experiences are able to discriminate spectrally complex acoustic signals, in addition to experiencing an improvement in short-term cognitive processing and speech recognition in noise.

Therefore, musical practice plays an important role in the development of auditory skills, also shaping skills that are indispensable in the social and academic development.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Brescia VP. Educação Musical: bases psicológicas e ação preventiva. 2nd rev; 2003. Alínea; p. 148.
2. Todres ID. Music is medicine for the heart. J Pediatr (Rio J). 2006;82:166–8.
3. Rizzo SC, Fernandes E. Neurociência e os benefícios da música para o desenvolvimento cerebral e a educação escolar. RPGM. 2018;1:13–20.
4. Pereira LD. Avaliação do processamento auditivo central. In: Lopes Filho O, editor. Novo Tratado de Fonoaudiologia. 3º ed Barueri: Manole; 2013. p. 179–95.
5. Martins JS, Pinheiro MMC, Blasi HF. A utilização de um software infantil na terapia fonoaudiológica de Distúrbio do Processamento Auditivo Central. Rev Soc Bras Fonoaudiol. 2008;13:398–404.
6. Sartori AA, Delecrode CR, Cardoso ACV. Processamento auditivo (central) em escolares das séries iniciais de alfabetização. CoDAS. 2019;31:e20170237.
7. Engel AC, Bueno CD, Sleifer P. Treinamento musical e habilidades do processamento auditivo em crianças: revisão sistemática. Audiol Commun Res. 2019;24:e2116.
8. Boéchat EM. Sistema auditivo nervoso central: plasticidade e desenvolvimento. In: Boéchat EM, Menezes PL, Couto CM, Frizzo ACF, Scharlach RC, Anastásio ART, editors. Tratado de audiologia. Rio de Janeiro: Santos; 2015. p. 15–20.
9. Mendonça JE, Lemos SMA. Relações entre prática musical, processamento auditivo e apreciação musical em crianças de cinco anos. Revista da ABEM. 2010;18:58–66.
10. Eugênio ML, Escalda J, Lemos SMA. Desenvolvimento cognitivo, auditivo e linguístico em crianças expostas à música: produção de conhecimento nacional e internacional. Rev CEFAC. 2012;14:992–1003.
11. Carvalho NG, Novelli CV, Colella-Santos MF. Fatores na infância e adolescência que podem influenciar o processamento auditivo: revisão sistemática. Rev CEFAC. 2015;17:1590–603.
12. Escalda J, Lemos SMA, França CC. Habilidades de processamento auditivo e consciência fonológica em crianças de cinco anos com e sem experiência musical. J Soc Bras Fonoaudiol. 2011;23:258–63.
13. Pantev C, Oostenveld R, Engelien A, Ross B, Roberts LE, Hoke M. Increased auditory cortical representation in musicians. Nature. 1998;392:811–4.
14. Gaser C, Schlaug G. Brain structures differ between musicians and nonmusicians. J Neurosci. 2003;23:9240–5.

15. Lappe C, Herholz S, Trainor L, Pantev C. Cortical plasticity induced by short-term unimodal and multimodal musical training. J Neurosci. 2008;28:9632–9.
16. Lappe C, Trainor L, Herholz S, Pantev C. Cortical plasticity induced by short-term multimodal musical rhythm training. PLoS One. 2011;6:21493.
17. George EM, Coch D. Music training and working memory: an ERP study. Neuropsychologia. 2011;49:1083–94.
18. Alves WA, Rei TG, Boscolo CC, Donicht G. Influência da prática musical em habilidades do processamento auditivo central: uma revisão sistemática. Distúrb Comun. 2018;30:364–75.
19. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati (deceased) A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4:1.
20. Pithon MM, Sant'Anna LIDA, Baião FCS, Santos RL, Coqueiro RS, Maia LC. Assessment of the effectiveness of mouthwashes in reducing cariogenic biofilm in orthodontic patients: a systematic review. J Dent. 2015;43:297–308.
21. Faßhauer C, Frese A, Evers S. Musical ability is associated with enhanced auditory and visual cognitive processing. BMC Neurosci. 2015;16:59.
22. Brown CJ, Jeon EK, Driscoll V, Mussoi B, Deshpande SB, Gfeller K, et al. Effects of long-term musical training on cortical auditory evoked potentials. Ear Hear. 2017;38:e74–84.
23. Meha-Bettison K, Sharma M, Ibrahim RK, Vasuki PRM. Enhanced speech perception in noise and cortical auditory evoked potentials in professional musicians. Int J Audiol. 2018;57:40–52.
24. Suppanen E, Huotilainen M, Ylinen S. Rhythmic structure facilitates learning from auditory input in newborn infants. Infant Behav Dev. 2019;57:101346.
25. Habibi A, Cahn BR, Damasio A. Neural correlates of accelerated auditory processing in children engaged in music training. Dev Cogn Neurosci. 2016;21:1–14.
26. Kraus N, Strait DL. Emergence of biological markers of musicianship with school-based music instruction. Ann N Y Acad Sci. 2015;1337:163–9.
27. Slater J, Skoe E, Strait DL, O'Connell S, Thompson E, Kraus N. Music training improves speech-in-noise perception: Longitudinal evidence from a community-based music program. Behav Brain Res. 2015;291:244–52.
28. Soncini F, Costa MJ. Efeito da prática musical no reconhecimento da fala no silêncio e no ruído. Pró-Fono R Atual Cient. 2006;18:161–70.
29. Nascimento FM, Monteiro RAM, Soares CD, Ferreira MID. Temporal sequencing abilities in musicians violinists and non-musicians. Intl Arch Otorhinolaryngol. 2010;14:217–24.
30. Moreno S, Wodniecka Z, Tays W, Alain C, Bialystok E. Inhibitory control in bilinguals and musicians: event related potential (ERP) evidence for experience-specific effects. PLoS One. 2014;9:e94169.
31. Mishra SK, Panda MR, Herbert C. Enhanced auditory temporal gap detection in listeners with musical training. J Acous Soc Am. 2014;136. EL173-8.
32. Rabelo CM, Neves-Lobo IF, Rocha-Muniz CN, Ubiali T, Schochat E. Cortical inhibition effect in musicians and non-musicians using P300 with and without contralateral stimulation. Braz J Otorhinolaryngol. 2015;81:63–70.
33. Ribeiro ACM, Coelho SR, Canina PMM. Avaliação dos aspectos temporais em cantores populares. CoDAS. 2015;27:520–5.
34. Moreno S, Marques C, Santos A, Santos M, Castro SL, Besson M. Musical training influences linguistic abilities in 8-year-old children: more evidence for brain plasticity. Cereb Cortex. 2009;19:712–23.
35. Putkinen V, Tervaniemi M, Saarikivi K, Ojala P, Huotilainen M. Enhanced development of auditory change detection in musically trained school-aged children: a longitudinal event-related potential study. Dev Sci. 2014;17:282–97.
36. Moreno S, Lee Y, Janus M, Bialystok E. Short-term second language and music training induces lasting functional brain changes in early childhood. Child Dev. 2015;86:394–406.
37. Magne C, Schön D, Besson M. Musician children detect pitch violations in both music and language better than nonmusician children: behavioral and electrophysiological approaches. J Cogn Neurosci. 2006;18:199–211.
38. Curtin S, Campbell J, Hufnagle D. Mapping novel labels to actions: how the rhythm of words guides infants' learning. J Exp Child Psychol. 2012;112:127–40.
39. Spinelli M, Fasolo M, Mesman J. Does prosody make the difference? A meta-analysis on relations between prosodic aspects of infant-directed speech and infant outcomes. Dev Rev. 2017;44:1–18.
40. Schon D, Tillmann B. Short-and long-term rhythmic interventions: perspectives for language rehabilitation. Ann N Y Acad Sci. 2015;1337:32–9.
41. Zendel BR, West GL, Belleville S, Peretz I. Musical training improves the ability to understand speech-in-noise in older adults. Neurobiol Aging. 2019;81:102–15.
42. Freire KGM. Treinamento auditivo musical: uma proposta para idosos usuários de próteses auditivas [tese]. São Paulo: Universidade Federal de São Paulo; 2009.
43. Hennig TR, Costa MJ, Rossi AG, Moraes AB. Efeitos da reabilitação auditiva na habilidade de ordenação temporal em idosos usuários de próteses auditivas. J Soc Bras Fonoaudiol. 2012;4:26–33.
44. Lessa AH, Hennig TR, Costa MJ, Rossi AG. Resultados da reabilitação auditiva em idosos usuários de próteses auditivas avaliados com teste dicótico. CoDAS. 2013;25:169–75.
45. Zendel BR, Alain C. Musicians experience less age-related decline in central auditory processing. Psychol Aging. 2012;27:410–7.
46. Zatorre RJ, Chen JL, Penhume VB. When the brain plays music: auditory-motor interactions in music perception and production. Nat Rev Neurosci. 2007;8:547–58.
47. Schlaug G, Jancke L, Huang Y, Staigeri JF, Steinmetz H. Increased corpus callosum size in musicians. Neuropsychologia. 1995;33:1047–55.
48. Schlaug G, Forgeard M, Zhu L, Norton A, Norton A, Winner E. Training-induced neuroplasticity in young children. Ann N Y Acad Sci. 2009;1169:205–8.
49. Hyde KL, Lerch J, Norton A, Forgeard M, Winner E, Evans AC, et al. The effects of musical training on structural brain development. Ann N Y Acad Sci. 2009;1169:182–6.
50. Pooviboonsuk P, Dalton JA, Curran HV, Lader MH. The effects of single doses of lorazepam on event-related potentials and cognitive function. Hum Psychopharmacol. 1996;11:241–52.