CLINICS

REVIEW

Effects of different types of auditory temporal training on language skills: a systematic review

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Previous studies have investigated the effects of auditory temporal training on language disorders. Recently, the effects of new approaches, such as musical training and the use of software, have also been considered. To investigate the effects of different auditory temporal training approaches on language skills, we reviewed the available literature on musical training, the use of software and formal auditory training by searching the SciELO, MEDLINE, LILACS-BIREME and EMBASE databases. Study Design: Systematic review. Results: Using evidence levels I and II as the criteria, 29 of the 523 papers found were deemed relevant to one of the topics (use of software – 13 papers; formal auditory training – six papers; and musical training – 10 papers). Of the three approaches, studies that investigated the use of software and musical training had the highest levels of evidence; however, these studies also raised concerns about the hypothesized relationship between auditory temporal processing and language. Future studies are necessary to investigate the actual contribution of these three types of auditory temporal training to language skills.

KEYWORDS: Training; Hearing; Language, Music; Software.

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INTRODUCTION

Since the 1990s, research has supported the hypothesis, initially proposed by Tallal & Piercy (1), that language disorders are related to a deficit in auditory temporal processing (2-4). According to Habib (4), difficulties are observed in the processing of the temporal characteristics of different types of sensory stimuli, including auditory, visual and sensory-motor stimuli, when the stimuli are presented in rapid succession. More specifically, difficulty involving auditory temporal processing is expressed as a limited capacity to process ''short acoustical elements'', such as consonants, that comprise the rapid transition of formants. Limitations in this capacity can lead to difficulties, such as associating letters with their specific sounds, which can potentially result in dyslexia.

Based on this hypothesis, a large number of studies have investigated the effects of auditory temporal training on language skills (5-23). One topic that is still being actively debated concerns the effectiveness of new approaches to auditory training, such as the use of software (5-17) and musical training (24-33), compared with more traditional types of auditory training (18-23) that take place in acoustic cabins (''formal auditory training''). Currently, no consensus has been reached regarding the most effective approach to improving language skills such as phonological awareness, reading and speech discrimination.

The purpose of this paper is to perform a systematic review of the effects of different types of auditory temporal training on language skills; we focus on three main approaches: the use of software, formal auditory training and musical training.

METHOD

For this systematic review, a search was performed between March and April 2013 for papers published in Portuguese, English and Spanish. The following databases were searched: MEDLINE, SciELO, EMBASE and LILACS-BIREME. The keywords used in the search included ''dyslexia'', ''language skills'', ''poor readers'', ''literacy'', ''learning'', ''learning impairment'', language impairment'', ''music education'', ''computer-based auditory training'', ''auditory intervention'', ''auditory temporal processing'', ''musical training'', ''language'' and the corresponding words in Portuguese and Spanish. In addition to the keywords listed above, ''auditory perceptual disorders'' and ''language development disorders'' were also included in a search of MeSH (Medical Subject Headings). There were no date restrictions, and the keywords were always combined. For selection from the search results, papers had to: include a main goal of investigating the effects of

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Table 1 - Levels of evidence of the treatment efficacy studies (ASHA, 2004).

Level	DESCRIPTION
Ia	Well-designed meta-analysis of randomized controlled trials
Ib	Well-designed randomized controlled trials
IIa	Well-designed controlled studies without randomization
IIb	Well-designed quasi-experimental studies
III	Well-designed non-experimental studies, i.e., correlational and case studies
IV	Expert committee reports, consensus conferences and clinical experiences of respected authorities

training on auditory and/or language skills, contain a description of the type of intervention and the post-training implications and be classifiable as level I or II in the evidence hierarchy proposed by American Speech-Language-Hearing Association (34), which is presented in Table 1.

RESULTS

From a sample of 523 papers, 29 original papers classified as evidence levels I and II were included. The results will be discussed within the context of the type of training employed. We found papers related to the use of software (13 papers), formal auditory training (six papers) and musical training (10 papers).

Use of software

Table 2 shows the 13 papers that investigated auditory temporal training using different types of software (5-17). All of the papers included were randomized and/or controlled trials; therefore, these papers belonged to evidence levels I and II. Differences in the study groups (typically developing children, children with dyslexia, children with language impairment and learning impairment and adults with schizophrenia), types of software used (*Fast ForWord, Earobics, AudioTraining, Treinamento Temporal Auditivo com estímulos não-verbais e verbais com fala expandida, STAR and others based on the Fast ForWord*) and study designs, such as the inclusion of a comparison training group and the types of pre- and post-assessments, are systematized in the table.

Of these 13 papers, 10 included auditory temporal processing and language assessment before and after training (5,7,10-17). Of these 10 papers, 7 indicated learning gains in auditory and language skills only in the study group after training based on behavioral (5,10,13,16) and electrophysiological measures (12,15,17). Therefore, these findings support the hypothesized relationship between auditory temporal processing and language skills (5,10,12,13,15-17). However, relevant methodological concerns are present in some of these studies. Tallal et al. (5), Fisher et al. (13) and Strehlow et al. (16) did not investigate the presence of a test-retest effect by including a non-trained group (control group). Additionally, Heim et al. (12), Russo et al. (15) and Hayes et al. (17) did not include an alternative training group to investigate whether the improvement after training was specifically related to the type of training, for example, auditory temporal training. Murphy and Schochat (10) investigated the influence of non-verbal auditory training on language skills in two experiments. In the first experiment, only the group of children with dyslexia that underwent auditory temporal training exhibited improvement in language skills compared to an untrained control group; in the second experiment, a group of children with dyslexia exhibited improvement in language skills following auditory training, but not after a period with an alternative intervention (language training). The other three studies reached varying conclusions: in the Gillan et al. study (7), auditory and language skill improvement occurred for all of the trained groups of children with language disorders (i.e., the study group and the alternative groups) demonstrating that the auditory temporal training was as effective as language training; in the Halliday et al. study (11), although the trained group (children with typical development) exhibited improvements in auditory temporal processing after training, this learning did not generalize to the language skills, which casts doubt on the use of auditory training to improve language; in the Gaab et al. study (14), although there was no gain in auditory skills after training, the language skills of the children with dyslexia improved. Therefore, the authors discussed whether the improvement in language after training might have been related to the improvement of indirectly trained skills, such as cognitive skills, rather than sensory capacity, such as auditory temporal processing.

The other three studies only investigated language skills after auditory temporal training (6,8,9). Cohen et al. (6) reported improvements in language skills for all groups (including a non-trained group), which may indicate the presence of a test-retest effect; Given et al. (8) corroborated the results of Gillan et al. (7) by reporting improvements following all types of training, which indicates that the success of training in terms of improving language skills is not necessarily related to a specific focus on temporal aspects; Pinheiro & Capellini (9) reported an improvement in the trained group only, although there was no alternatively trained group for comparison in this study.

Formal auditory temporal training

Table 3 shows the six papers that investigated the effectiveness of formal auditory temporal training (using an acoustic cabin) (18-23). The samples were diverse and included children with language disorders, children with auditory processing disorders and adult and elderly hearing aid users. All papers were controlled, with high levels of evidence (I or II) according to the ASHA criteria (34).

Of the six papers, only one analyzed auditory temporal processing and language following auditory temporal training (19). The researchers applied the auditory training to a group of adult hearing aid users. Compared to the untrained group, the results showed that the trained group exhibited improvements in temporal processing after training that were verified by electrophysiological measures of auditory function (reduced of P3 latencies). The trained group also exhibited improvements in language that were verified by the application of a self-assessment questionnaire that quantified auditory difficulties experienced in daily situations involving communication in quiet, noisy and reverberant environments.

Table 2 - Auditory temporal training using different types of software.

Study	Evidence Level	Participants			Age	Improvement of ATP after training?	Improvement of language skills after training?
		SG	AG	CG			
Tallal et al. (5)	II	11 Lang D (FFW)	11 Lang. D (software with natural speech)	______	5 to 10	Yes, higher for SG	Yes, higher for SG
Cohen et al. (6)	Ib	23 Lang.D (FFW)	1 group of 27 Lang. D (another software)	1 group of 27 Lang. D	6 to 10	Not tested	Yes, for all 3 trained groups
Gillam et al. (7)	Ib	54 Lang. D (FFW)	3 groups of 54 Lang. D each (another software)	______	6 to 8	Yes, for all trained groups	Yes, for all 4 trained groups
Given et al. (8)	Ib	12 Lang. D (FFW)	3 groups of 14, 15 e 11 Lang. D each (another software)	1 group of 13 Lang. D	12	Not tested	Yes, for all 4 trained groups
Pinheiro & Capellini (9)	II	10 Learn. D (AudioTraining) e 10 TD (AudioTraining)	______	10 Learn. D e 10 TD	8 to 14	Not tested	Yes, only for SG
Murphy & Schochat (10)	II	Study 1-12 D (Software ATP) Study 2-18 D (Software ATP)	Study 2-18D (language training)	Study 1-28 D	7 to 14	Study 1 – Yes, only for SG Study 2 – Yes, only for SG	Study 1 – Yes, only for SG Estudo 2 – Yes, only for SG
Halliday et al. (11)	II	22 TD (non-verbal discrimination/Software STAR)	2 groups of 22 TD (verbal discrimination) and 20 TD (visual discrimination)	1 group of 22 TD	8 to 10	Yes, only for SG and one of the AG	No improvement
Heim et al. (12)	II	21 Lang D (FFW)	______	1 group of 12 TD	8 (mean age)	Yes, only for SG	Yes, only for SG
Fisher et al. (13)	II	29 schizophrenia (based on the FFW)	1 group of 26 schizophrenia (visualspacial game, pinball-style game)	______	45 (SG) and 48 (AG)	Yes, only for SG	Yes, only for SG
Gaab et al. (14)	II	22 D (FFW)	______	1 group of 23 TD	10 (mean age)	No	Yes, only for SG
Russo et al. (15)	II	9 Lear. D. (Earobics)	______	1 group of 10 TD and Lear. D.	8 to 12	Yes, only for SG	Yes, only for SG
Strehlow et al. (16)	II	15 D (sound processing training and reading)	14 D (phoneme processing and reading) and 15 D (reading)	______	7 to 8	Yes, for all but higher for sound processing group after 6 or 12 months later	Yes, for all groups after 12 months later
Hayes et al. (17)	II	27 Learn. D (Earobics)	______	15 learn. D. and 7 TD	8 to 12	Yes, higher for SD	Yes, for some measures in SG

SG: study group; AG: alternative group; CG: control group; Lang. D: language disorder; Learn. D: Learning disorder; D: dyslexia; ATP: auditory temporal processing; FFW: *Fast Forword Training*; TD: typically development; Software ATT: software auditory temporal processing.

Table 3 - Formal auditory temporal training.

Study	Evidence Level	Participants			Age	Improvement of ATP after training?	Improvement of language skills after training?
		SG	AG	CG			
Megale et al. (18)	II	16 HAU	_____	13 HAU	60 to 90	Not tested	Yes, qualitative improvement only for SG
Gil & Iório (19)	II	7 HAU	_____	7 HAU	16 to 60	Yes, reduction of P3 latency only for SG	Yes, qualitative improvement only for SG
Filippini et al. (20)	II	9 APD and 6 Lang. D	_____	7 TD and 8 Lang. D.	7 to 12	Yes, only for trained groups	Not tested
Vilela et al. (21)	Ib	5 PD	5 PD (informal training)	5 PD	7 to 10	no significant differences before and after training for all groups	Not tested
Miranda et al. (22)	II	6 HAU	______	7 HAU	60 to 74	Yes, for SG	Not tested
Schochat et al. (23)	II	30 APD		23 TD	8 to 14	Yes, for SG	Not tested

SG: study group; AG: alternative group; CG: control group; ATP: auditory temporal processing; HAU: hearing aid users; Lang. D.: language disorder; APD: auditory processing disorder; PD: phonological disorder; TD: typically development.

Table 4 - Musical training.

Study	Evidence Level	Participants			Age	Improvement of ATP after training?	Improvement of language skills after training?
		SG	AG	CG			
Overy et al. (24)	II	9 D	________	15 weeks of SG before musical training	8,8 (average)	Yes, after training	Yes (phonological skills only after training)
Degé & Schwarzer (25)	II	13 TD	14 (phonological training) e 14 (sports training)	_____	5 to 6	Not tested	Yes (phonological awareness in SG and phonological AG)
Gerry et al. (26)	Ib	20 TD active musical training	14 TD (passive musical training)	26 TD	6 months (average)	Improvement of musical discrimination	Yes (gestures in SG)
Moreno & Besson (27)	II	10 TD	10 TD (training in painting)	8 TD	8y (average)	Yes, electrophysiological tests	Not tested
Yucel et al. (28)	II	9 CI	_______	9 CI	8 months to 8 years	Yes, greater for SG	Yes (greater for SG)
Moreno et al. (29)	II	16 TD (musical training)	16 TD (painting training)	_____	8,4 (average)	Yes, for SD	Yes, for SD
Chobert et al. (30)	II	12 TD (musical training)	12 TD (painting training)	______	8 (average)	Yes, for SG	Not tested
Bolduc (31)	II	51 TD (Standley and Hughes music training programme)	53 TD (government music program)	_______	5 (average)	Yes, for both groups	Yes, higher for SG
Fujioka et al. (32)	II	6 TD (Suzuki music school)	______	6 TD	4 to 6	Yes, for SG	Not tested
Gromko (33)	II	43 TD (music education)	________	60 TD	kindergarten	Not tested	Yes, higher for SG

SG: study group; AG: alternative group; D: dyslexia; ATP: auditory temporal processing; TD: typically development; CI: cochlear implant.

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Of the other five papers, one investigated the effects of formal auditory training on language skills (18), and the other four investigated the effects on auditory skills (20-23). Megale and Schochat (18) investigated the effectiveness of formal auditory training in elderly hearing aid users and reported effects similar to those of the Gil & Iorio study (19). Using the Abbreviated Profile of Hearing Aid Benefit (APHAB) self-report scale, these researchers also demonstrated qualitative improvements in language skills after training. Auditory temporal skills were not investigated, but auditory closure and auditory figure-ground skills improved after training.

Of the other four papers, three reported gains in auditory temporal processing after training using electrophysiological (20,23) and behavioral measures (20,22). Filippini et al. (20) applied formal auditory training to groups of children with both language and auditory processing disorders; in contrast to the untrained group, both of the trained groups showed improvements in auditory temporal skills after training, as demonstrated by improved performance in behavioral measures of auditory processing and a reduction of the latency of the auditory brainstem response to complex sounds in background noise (c-ABR). Like Gil & Iorio (19) and Megale et al. (18), Miranda et al. (22) applied formal auditory training to a group of elderly hearing aid users and compared that group to a non-trained group (control group) of elderly hearing aid users. The results of this study also indicated greater gains in auditory skills in the trained group compared to the control group. In contrast, Villela et al. (21) compared children with phonological disorders who received formal auditory training to children who received alternative training (informal training) and an untrained group. Neither of the trained groups exhibited any significant differences in auditory temporal skills before and after training, a result that was likely related to the small sample of participants in the study.

All studies applied formal auditory training using similar materials (compact discs with tasks involving auditory closure, temporal ordering, figure to ground for digits, sentences and non-verbal sounds) and the procedures employed by Musiek and Schochat (35).

Musical training

Table 4 lists 10 papers that investigated musical training and that were classified as evidence level I or II (24-33). Infants, typically developing children, children with dyslexia and children with cochlear implants were included.

Of the ten papers selected, five investigated auditory temporal skills and language skills before and after music training (24,26,28,29,31), and all of these papers reported gains in both skills. Three of these studies investigated the effect of music training on infants and children with typical development (26,29,31). For example, Gerry et al. (26) compared the effects of passive musical experiences (just listening to music) and active musical experiences (singing lessons, practice with percussion instruments and rhythm classes) in six-month-old-infants. Both groups were compared to an untrained group. The results demonstrated that, compared to infants assigned to the passive musical experience, the active group showed superior development of prelinguistic communication gestures and social behavior after training. Additionally, the active training group exhibited accelerated acquisition of knowledge about Western musical tonality and exhibited improvements in pitch discrimination after active training. In the Moreno et al. (29) and Bolduc (31) studies, music training was applied to groups of children who were compared to alternative groups that received either painting training (29) or alternative musical training (31). Moreno's study reported that, after musical training, the study group showed enhanced reading and pitch discrimination skills in speech as indicated by the amplitudes of specific event-related potential components elicited in music and speech tasks. The authors concluded that the results indicated brain plasticity by showing that relatively short periods of training (24 weeks) had strong effects on the functional organization of the children's brains. In the Bolduc study (31), after a specific music training program (Standley and Hughes music training), the study group exhibited gains in tonal and rhythmic perceptive skills and phonological awareness skills.

The positive effects of music training on language and auditory skills have also been demonstrated in infants and children with specific impairments, such as children with dyslexia (24) and profoundly deaf infants with cochlear implants (28). Overy et al. (24) analyzed the effect of musical training on children with dyslexia and reported a significant improvement in auditory temporal skills after training that was verified with tasks involving rapid auditory processing and phonological skills. The authors suggested that timing skills might play a key role in the transfer of musical abilities to language abilities. Yucel et al. (28) applied musical training to infants and children with cochlear implants. To investigate the effects of the training, language and auditory temporal processing assessments were performed before and after training and were compared between the trained group and an untrained control group. The researchers that the music group showed greater improvements in the discrimination of pairs of notes and greater improvements on tests that examined different levels of speech perception.

Of the other five studies, three only investigated auditory skills after training (27,30,32), and the other two only investigated language skills (25,33). All of the studies of auditory skills indicated gains in these skills after training. For example, in Moreno & Besson's study (27), the effect of musical training on typically developing children was compared with the effects of an alternative type of training (training in painting) and no training (i.e., an untrained control group). Electrophysiological measures of auditory function were assessed before and after training in all groups, and the results indicated that the amplitude of a late positive component was largest in response to strong incongruities; however, this amplitude was reduced after training only in the music group. Chobert et al. (30) applied active musical training in to children with typical development, and the mismatch negativities (MMNs) assessed before and after training were compared to a control group. While no between-group differences were identified before training, enhanced pre-attentive processing of syllabic duration and voice onset time, as reflected by greater MMN amplitudes, was noted after 12 months of training only in the music group. Fujioka et al. (32) also investigated auditory cortical responses (auditory evoked potentials) before and after one year of musical lessons. According to these authors, a clear musical training effect was expressed as a larger and earlier N250m peak in the left hemisphere in response to the sound of a violin in the musically trained children compared to the untrained children. The other two studies on the effects of music training on language skills also indicated gains after training (25,33). Dege and Schwarzer (25) studied the effects of musical training and the effects of two alternative types of training (phonological awareness and sports) on language skills in typically developing children. The results indicated improvements in phonological awareness after training in both the study group and the phonological awareness group. In the Gromko study (33), kindergarten children who received four months of music instruction showed significantly greater gains in the development of their phoneme segmentation fluency compared to children who did not receive music instruction.

DISCUSSION

Most of the papers that investigated the use of software demonstrated that this approach can be an effective form of training for improving auditory temporal processing (5,7,10-13,15-17). However, whether this learning generalizes to language skills remains controversial (5-10,12-17). For example, in some studies, the language improvements observed after training related to test-retest effects (6), but in other studies, these improvements seemed to result from any type of training and were not specific to auditory temporal training (7,8). Additionally, variables such as the duration of the training, the characteristics of the software, the type of the training and the assessment measures applied before and after training are likely important and intensify concerns regarding the genuine influence of auditory temporal training on language skills.

Few studies were found that employed formal auditory training using an acoustic cabin (18-23). Of these few papers, only one investigated performance on both auditory and language tests after training, but only in a qualitative manner (19). A few other limitations were also noted. First, although the studies had non-trained control groups, most of the studies did not have alternative groups, which are essential for comparing the influence of the main training with the influences of other types of training. Second, the small numbers of participants call into question the statistical power of the results. Therefore, our review of the current literature indicates that few definitive conclusions can be drawn about the effects of this approach on language skills.

Regarding musical training, of the ten studies that investigated language performance after training, most described improvements in language skills in the individuals who underwent musical training (24-26,28,29,31,33). Nevertheless, of these seven studies, only five investigated whether the improvements also occurred after auditory temporal training (24,26,28,29,31), and only one included an alternative type of training and a non-trained group (26). Therefore, although all of the studies reported positive effects of training on language skills, additional studies are needed that include alternative training groups, large samples and standardized musical training to replicate the current findings.

Another topical issue regarding auditory training is the fact that, in general, perceptual training methods of this type include simultaneous training of several perceptual, cognitive and linguistic skills. For example, in interventions intended to improve spectro-temporal auditory processing deficits in individuals with dyslexia (5), the training exercises were designed to also include specific components of linguistic processing and attention and memory skills. Therefore, results based on these interventions reveal whether the combination of all of the training tasks contributed to the improvements observed after training or whether the same results would have been obtained after training only a single skill. Further studies should include broader top-down skill assessments that incorporate, for example, attention and working memory tasks, before and after training. Only then will it be possible to investigate the extent to which auditory training influences other skills that are also related to language development.

When comparing the three approaches, it should be noted that the studies involving software and musical training had higher levels of evidence (level I) because some of these studies included alternative trainings and larger samples. Nevertheless, the software approach remains the most controversial because since the majority of the studies of this approach called into question the hypothesized relationship between auditory temporal processing and language; for example, research has demonstrated that not only auditory temporal training but also alternative types of training that are not related to auditory temporal processing lead to improvements in language skills. These results also address the influences of other top-down skills, as discussed previously. Because all types of perceptual training are likely to lead to gains in memory and attention capacity, language skills seem to improve regardless the type of training applied. It is also notable that there were no blind studies in any of the approaches, which indicates the need for more studies with higher levels of evidence.

In conclusion, based on our review of the current literature, the studies that investigated the use of software and musical training had the highest levels of evidence and, consequently, the most reliable data regarding the auditory temporal processing hypothesis. Each of the approaches requires additional studies that employ alternative training groups and blind designs to investigate the actual contribution of auditory temporal training to language skills.

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AUTHOR CONTRIBUTIONS

Murphy CF and Schochat E collected the data and wrote the manuscript.

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