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Literature Review

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Central auditory processing and reading processes in children and adolescents: integrative review

Processamento auditivo central e processos de leitura em crianças e adolescentes: revisão integrativa

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ABSTRACT

Purpose: To review studies investigating the existing interface between central auditory processing and reading processes in children and adolescents. **Research strategy:** Studies published from 2008 to 2019 were selected through a bibliographic survey in the following electronic databases: BVS - Lilacs (Virtual Health Library) and PubMed (US National Library of Medicine). **Selection criteria:** Studies available in full; published in Portuguese, English or Spanish; performed with children or adolescents; and that addressed the central auditory processing interfaces and reading processes. Literature review articles and articles with a lower level of scientific evidence were excluded. **Results:** A total of 1124 studies were found in the databases searched. Of these, 19 were excluded as they were on more than one base. The titles and abstracts of 1105 articles were analyzed, of which 92 were selected for full reading and, at the end, 46 articles were selected. In the review, it was observed that most studies were cross-sectional, evaluated temporal processing skills and compared groups of students with and without reading difficulties. **Conclusion:** Studies have shown that there is an association between reading and listening skills, as difficulty in listening skills tasks is common in participants with reading skills difficulties.

Keywords: Auditory perception; Hearing tests; Reading; Child; Adolescent development

RESUMO

Objetivos: Revisar estudos que investigaram a interface existente entre processamento auditivo central e processos de leitura em crianças e adolescentes. **Estratégia de pesquisa:** Foram selecionados estudos publicados no período de 2008 a 2019, por meio de levantamento bibliográfico nas bases de dados eletrônicas BVS - Lilacs (Biblioteca Virtual em Saúde) e PubMed (US National Library of Medicine). **Critérios de seleção:** Estudos disponíveis na íntegra; publicados em português, inglês ou espanhol; realizados com crianças ou adolescentes e que abordaram as interfaces de processamento auditivo central e processos de leitura. Foram excluídos artigos de revisões de literatura e artigos com menor nível de evidência científica. **Resultados:** Foram encontrados 1124 estudos nas bases de dados pesquisadas. Destes, 19 foram excluídos, pois estavam em mais de uma base. Analisaram-se os títulos e resumos de 1105 artigos, sendo que 92 foram escolhidos para a leitura na íntegra e, ao final, 46 artigos foram selecionados. Na revisão, observou-se que a maior parte dos estudos era de delineamento transversal, avaliava habilidades do processamento temporal e realizava comparação entre grupos de escolares com e sem dificuldades em relação à leitura. **Conclusão:** Os estudos revelaram que existe associação entre leitura e habilidades auditivas, à medida que a dificuldade em tarefas de habilidades auditivas é comum em participantes com dificuldades em habilidades de leitura.

Palavras-chave: Percepção auditiva; Testes auditivos; Leitura; Criança; Desenvolvimento do adolescente

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INTRODUCTION

Central auditory processing is a skill set that allows the listener to interpret the heard message in and efficient and effective way[1,2]. Among the skills encompassed by it are those of temporal processing, essential for language comprehension and speech development[3].

Central auditory processing disorders are often related to learning difficulties and language disorders[1,4-7]. The study of the relationship between reading processes and auditory skills is justified, as reading is an important way of acquiring new knowledge, and both are essential for learning[8,9]. In addition, the evaluation of central auditory processing in school children with learning difficulties is important as it contributes to an accurate diagnosis and thus to the best therapeutic process[1].

It should be emphasized that reading refers to a way of acquiring information, with the ultimate goal of understanding a written text[10]. For such end, a key aspect is reading comprehension, considered a process of recognition, integration and construction of ideas[11]. Furthermore, reading comprehension plays an important role in the literacy process and encompasses several interrelated cognitive processes, namely: the ability to process, store and retrieve information; memory, attention, reasoning, logic, central and visual auditory processing ability. Among these, there are jointly the basic processes of reading, such as recognition, that is, the decoding of words and the extraction of their meaning in printed form, which, although they are necessary requirements, are not sufficient for understanding to occur[12-14].

Among the skills required for the acquisition of reading and writing is the phonological awareness, characterized as the ability to segment words, syllables and phonemes[10], which is also closely related to the phonological reading route[11]. It is worth highlighting that the reading competence is developed in stages - logographic, alphabetical and orthographic - and with the utilization of different strategies - logographic, phonological and lexical[11].

Difficulties in phonological awareness are frequently associated with central auditory processing disorders[10]. The physiological mechanisms of hearing, in turn, play an important role in rapid acoustic processing, speech perception, learning and language comprehension, and are thus a prerequisite for the acquisition of reading and writing[10].

In light of the above, it can be seen that although the literature presents research that includes central auditory processing and reading, the main outcomes studied had not been mapped out yet, therefore it is timely to build a synthesis for the advancement of research in this area.

Objective

To review studies that investigated the interface between central auditory processing and reading processes in children and adolescents.

RESEARCH STRATEGY

This is an integrative literature review, based on national recommendations[15,16], aiming to answer the following question: "What is the relationship between central auditory processing and reading processes in children and adolescents?

The first phase of this research consisted in elaborating the question that guided the query. In order to obtain answers to this question, a bibliographic research was carried out using the Medline search platforms, through PubMed (US National Library of Medicine), and VHL - Lilacs (Virtual Health Library - Latin American and Caribbean Literature on Health Sciences). The data were collected from June to September, 2018 and January to December 2019.

The descriptors (MeSH - Medical Subject Headings - and DeCS - Health Sciences Descriptors) were applied, as well as the keywords "auditory temporal aspects" and "reading comprehension", to recover the subjects in literature. The descriptors and keywords were combined with the use of Boolean operators AND and OR. Therefore, the search equation used was: (tw:(("Percepção Auditiva" OR "Testes Auditivos" OR "Transtornos da Percepção Auditiva" OR "Aspectos temporais auditivos" OR "Auditory Perception" OR "Hearing Tests" OR "Auditory perceptual Disorders" OR "Temporal aspects of auditory"))) AND (tw:((leitura OR compreensão OR "Compreensão de Leitura" OR "Escrita Manual" OR escrita OR redação OR "Reading competence" OR reading OR comprehension OR handwriting OR writing))) AND (instance:"regional") AND (db:("LILACS" OR "IBECS" OR "INDEXPSI" OR "BINACIS" OR "LIS" OR "BBO" OR "CUMED" OR "DECS") AND la:("en" OR "pt" OR "es")).

SELECTION CRITERIA

In order to include the articles, the following criteria were adopted: studies available in full; published from 2008 to 2019; in Portuguese, English or Spanish; carried out with children or adolescents and that studied the central auditory processing interfaces and reading processes. The exclusion criteria adopted were: literature review articles and articles with a lower level of scientific evidence, as proposed by the literature[17], such as expert opinion articles, case reports or case series.

Data analysis

At first, the studies were selected based on the reading of the titles and abstracts. Later, the articles were read in full and the information was analyzed according to the checklist of the STrengthening the Reporting of OBservational Studies in Epidemiology - STROBE[18]. The objective of the STROBE initiative is to assist in the reporting of observational studies, through its checklist[18].

The following items constituted the protocol for analysis of studies: research objective, design, methods, analyzed variables and results. For this purpose, two authors performed the reading and analysis of the studies, and in cases where there were divergences regarding the inclusion or non-inclusion of the study, the results of the analysis were discussed with a third author.

RESULTS

There were 383 articles found in the BVS - Lilacs database and 741 articles in PubMed, totaling 1124 articles. Of these studies, 19 were excluded because they were present in more than one database. Through the analysis of the title and abstract, 1013 articles were excluded because they did not answer the guiding question of the study. As a consequence, 92 studies were chosen for reading in full. Of these, 46 were excluded because they did not answer the guiding question of the study. At the end, 46 articles were selected for the review (Figure 1). Although the guiding question for this review was the central auditory processing, most of the articles pointed to the temporal aspects of central auditory processing. In addition, this study revealed that most of the authors of the selected studies opted for simpler designs (cross-sectional studies).

Of the 46 studies selected for this review, 58.6% were international studies, 17 corresponded to cross-sectional observational studies, 4 experimental, 7 longitudinal, 2 exploratory, 14 control cases and 2 cohort. Another relevant data is that only 6 studies[19-24] did not perform comparisons between groups (Chart 1). In other words, these studies were carried out with children regularly enrolled in educational institutions[19-21,23,24], or with children suspected of central auditory processing disorder[22]. The other studies compared 2[26-32,34,36-43,45,49,51,54-58,61], 3[25,33,44,46-48,50,52,53,59,60] or 5[62] study groups. It was also found that in 4 studies[26,35,62,63] auditory training was carried out in groups with alterations: participants with reading difficulties[26] and with learning disorders[35,63]. In a single study[62], a comparison was made between 5 study groups, carrying out memory and attention skills training in addition to auditory training.

The results of this review indicated that only 11 studies[23,32,42,43,45,46,51,54,60,62,63] did not utilize tests that evaluate the temporal aspects of central auditory processing. Among the most commonly used tests to evaluate temporal aspects are the Gaps in Noise (GIN), the Frequency Pattern Test (TPF) and the Duration Pattern Test (DPT).

Regarding the design of studies, it was observed that most of them presented cross-sectional designs[10,19,20,22,24,25,27-34,37,38,49], followed by studies with case-control designs[39,43-45,50,51,53-56,58-61].

Among the studies selected for the present integrative review, a large part had as their settings the clinic or ambulatory of the educational institution. Several studies[19-21,23,24,31,36,39,40,45,49-55,57,60] had, at least, part of the data collection carried out in the school where the participants were enrolled. Nine studies[22,32,41-43,48,58,59,61] lacked the reference to the place of data collection.

DISCUSSION

According to the literature[9,64], central auditory processing tests have often been used to verify the association between school difficulties and changes in hearing skills development. For this reason, children with complaints of school difficulties usually present worse results in the evaluation of central auditory processing[64]. In the present literature review, most studies[10,25-35,37-40,44,45,47,48,50,51,53-58,60,63] evaluated central auditory processing skills in children and adolescents with learning disabilities or dyslexia. Most of the authors concluded that there is a change in central auditory processing in participants with dyslexia and with reading and writing disorders. However, no great differences were found between the performance of both groups, and it was always worse than the one found in the control group.

It is worth considering that central auditory processing encompasses several skills, including temporal processing skills[3]. Temporal aspects of hearing are essential for speech and language comprehension, and their inadequacy may be reflected in orthographic difficulties and in the coding/decoding of both words and phrases[3].

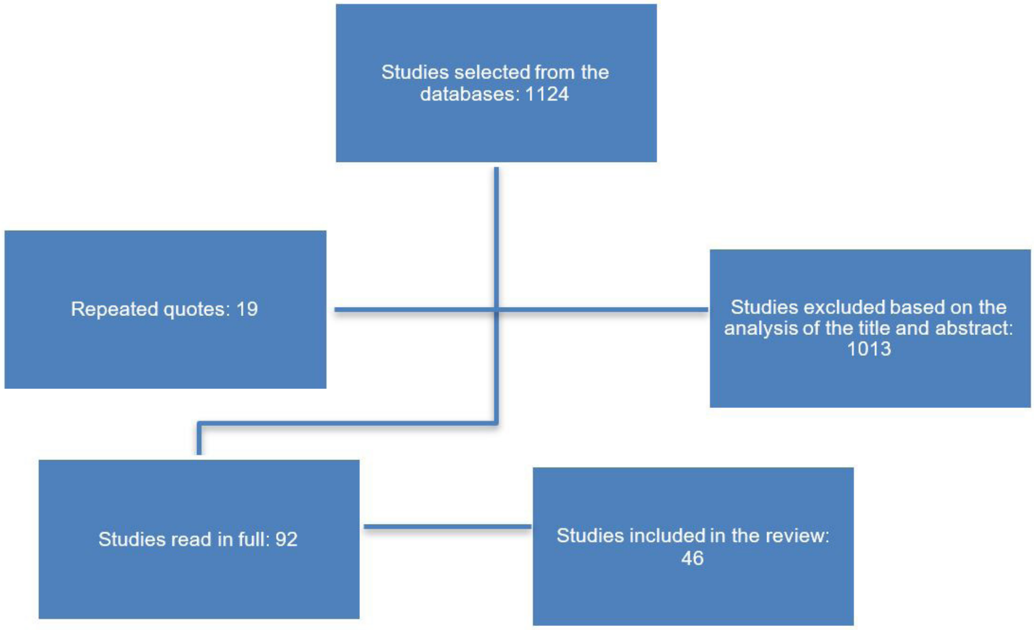

Figure 1. Flowchart of the study selection criteria

Chart 1. Description of the results of the selected studies

Author	Country	Design	Casuistic	Tools	Main findings of the study
Chaubet et al.[25]	Brazil	Cross-sectional	56 participants: 11 with dyslexia, 15 with reading and writing disorders and 30 from the group without change. Age range: 10-15 y.	Audiological assessment and GIN.	The GIN test similarly identified difficulty in individuals with reading and writing disorders and in individuals with dyslexia. The performance of the typical group was better than the other two.
Vatanabe et al.[26]	Brazil	Experimental	20 participants: 10 with reading difficulties and 10 without school difficulties. Age range: 8 y.	Initial and post auditory evaluation of TPF, DPT, GIN, Clinical Reading Protocol and PAT.	The auditory training was effective in improving temporal and reading skills in children who had reading difficulties.
Murphy-Ruiz et al.[27]	México	Cross-sectional	40 participants: 20 with dyslexia and 20 in a group without alterations. Age range: 7-11 y.	Assessment of writing and reading comprehension and accuracy; TPF and DPT, recognition of musical tone and identification of environmental sounds.	Children with dyslexia performed worse in all PAC tests when compared to the typical group, including those involving the right brain hemisphere.
Oliveira et al.[28]	Brazil	Cross-sectional	38 participants: 22 with dyslexia and 16 in a group without alterations.. Age range: 9-12 y	Complete audiological evaluation, PEATE, single word reading/reduced version test, text reading/adaptation test, FR test, TDD, TPF, P300.	The results suggested a change in temporal processing skills and figure-background in children with dyslexia.
Simões et al.[29]	Brazil	Cross-sectional	40 participants: 20 with dyslexia and 20 with TPAC. Age range: 7-12 y.	Audiological assessment, FR, TDD and TPF tests	The probability of change in FR and TDD tests was higher in the TPAC group than in the group with dyslexia. The TPF presented the same probability of change in both groups.
Boscariol et al.[30]	Brazil	Cross-sectional	20 participants: 11 with dyslexia and 9 in a group with no alterations. Age range: 8-14 y.	ABFW (phonology), reading and writing assessment (spontaneous writing, Phonological Skills Profile test, PCS), TDE, oral reading speed; peripheral audiological assessment, RGDT and/or RGDT Expanded.	It was found that children with developmental dyslexia could have altered auditory temporal processing, with damage to phonological processing.
Pelitero et al.[31]	Brazil	Cross-sectional	28 participants: 13 with learning change from reading and writing and 15 from the group without change. Age range: 8-12 y.	Otoscopy, audiological evaluation, TDE, ASPA and the PSI test.	More changes were observed in the AP tests in the group with learning alterations. However, there was no association with significance.

Subtitle: ABR = evoked response audiometry; ASPA = Simplified Evaluation of Auditory Processing; BioMARK = biological marker of auditory processing; DEL = specific language disorder; DEST = dyslexia early screening test; DFBP = low-pass filtered speech; DI = discrimination of intensity; DPA = auditory processing disorder; DPAC = central auditory processing disorder; DPT = Duration Pattern Tests; EEG = electroencephalogram; EOG = electrooculography; EOAPD = otoacoustic emissions per distortion product; EOAT = transient otoacoustic emission; FC = Concurrent Phrase Test; FM = detection of frequency modulation; FR = Noise Speech Test; GAP = interval; GIN = *Gaps in Noise*; LDN = late discriminative negativity; LiSN-S = Spatial Noise Sentence Test; MLD = masking level differences; MMN = Mismatch Negativity; MSNV = Memory Test for Non-Verbal Sounds in Sequence; MSV = Memory Test for Verbal Sounds in Sequence; OSCCI = spelling test; PA = auditory processing; PAT = Phonologic Awareness Test – Sequential Evaluation Instrument; PCS = Syntactic Consciousness Test; PEATE = Auditory Brainstem Evoked Potential; PPS = Pitch Pattern Sequence; PSI = Pediatric Logo-audiometry Test or Speech Intelligibility Test; QI = intelligence quotient; RAN = Fast Automatic Naming Test; RGDT = Random Gap Detection Test; RT = discrimination of sound rise time; SCAN = standardized test of auditory processing; SSW = Alternating Dissyllables Test; TCLPP = Pseudo-word and Word Reading Competence Test; TDD = Digits Dichotic Test; TDE = School Performance Test; TFR = Noise Figure Test; TOWRE = test of word reading efficiency; TPF = Frequency Pattern Tests; VCV = vowel-consonant-vowel; PAC = central auditory processing; TPAC = central auditory processing disorder; ABFW = children's language test in the areas of phonology, vocabulary, fluency and pragmatics; IMAP = test battery called IHR Multi-center Auditory Processing; TPA = auditory processing disorder; VOT = voice onset time; P300 = long latency auditory evoked potential.

Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Pinheiro et al.[32]	Brazil	Cross-sectional	40 participants: 20 with learning disability and 20 with good school performance.	Basic audiological assessment and TDD, SSW and FR tests.	The group of schoolchildren with learning disabilities performed less well than the group without difficulties, reflecting difficulties in processing auditory information.
			Age range: 8-12 y.		
Abdo et al.[33]	Brazil	Cross-sectional	30 participants: 10 with dyslexia, 10 with ADHD and 10 from the group without change.	Complete audiological evaluation, FR, TDD and TPF tests.	In TPF, children with dyslexia performed statistically worse than the typical group, suggesting the existence of a relationship between temporal abilities and reading disorder.
			Age range: 7-12 y.		
Pinheiro et al.[32]	Brazil	Experimental	40 participants: 20 with learning disability and 20 without learning disability. Each group was subdivided into two and only half of the participants received auditory training.	Audiological examination; TDD and SSW; CONFIAS.	Performance in auditory skills after the application of the auditory training program improved in participants with and without learning disabilities.
			Age range: 8-14 y.	The Audio Training® auditory training program was held.	
Frota et al.[10]	Brazil	Cross-sectional	60 participants: 30 with unfavorable results in at least one of the reading and writing tests and 30 in the group without change.	Basic audiological evaluation; Phonological Awareness Test; reading speed evaluation; reading aloud test; writing evaluation with dictation of real and invented words; understanding of narratives through the linguistic notion of figure-background; SSW Test; Dichotic Test; Sound Sequencing Test; and Localization Test for Non-Verbal Sounds.	In most central auditory processing tests, the performance of children without reading and writing disorders was better than the performance of the group with the deficit.
			Age range: 9-12 y.		
Murphy et al.[34]	Brazil	Cross-sectional	60 participants: 33 with dyslexia and 27 from the group without change.	Otoscopy, immittance and tonal and speech audiometry; frequency and duration discrimination tests, frequency and duration ordering.	The group with dyslexia showed significantly lower performance in all situations.
			Age range: 9-12 y.		

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Pinheiro et al.[35]	Brazil	Experimental	40 participants: 20 with learning disability and 20 without learning disability. Each group was subdivided into two and only half of the participants received auditory training.	Audiological evaluation; PSI TDD and SSW tests in pre- and post-test situations.	Schoolchildren with learning disabilities presented statistically significant changes. The performance of both groups, after auditory training, was statistically superior.
			Age range: 8-14 y.	Audio Training® Auditory Training Program.	Changes in BP directly interfere with the reception and decoding of information, reflecting delays in language development and learning to read and write in the classroom.
Engelmann et al.[36]	Brazil	Exploratory Cross-sectional	21 participants: 9 with more fluency in reading and 12 with less fluency in reading.	Basic audiological assessment; writing assessment; silent reading assessment; fluency and reading comprehension assessment; ASPA; TDD and SSW; PPS.	The study identified verbal sequential memory as a relevant aspect, by relating the scores of central auditory processing tests to the learning difficulties evidenced by lower reading fluency.
			Age range: 7-11 y.		
Germano et al.[37]	Brazil	Cross-sectional	20 participants: 10 with dyslexia and 10 with good academic performance.	Basic audiological examination, ASPA, PSI, TDD and SSW tests, Phonological Awareness Test.	The performance of the group with good academic performance was better than the group with dyslexia.
			Age range: 10 y. and 4 months (average age)		
Capellini et al.[38]	Brazil	Cross-sectional	20 participants: 10 with dyslexia and 10 with good academic performance.	Basic audiological examination; ASPA, PSI, TDD and SSW tests, Phonological Awareness Test.	School children with dyslexia presented difficulties in attention listening skills, coding, organization and integration of auditory information that compromised the use of phonological skills such as attention, analysis, synthesis, and work memory.
			Age range: 10 y and 4 months (average age)		

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Steinbrink et al.[19]	Germany	Cross-sectional	Study 1: 54 participants	Five musical tasks (temporal and tonal musical skills); phonological processing evaluation (phonological awareness, short-term and working phonological memory, speed of appointment).	In both studies, rhythm reproduction and pitch perception proved to be significant predictors of phonological awareness.
			Age range: 5 y. and 9 months (average age)		The results indicated that musical processing skills still contributed expressively to the prediction of the number of correctly written graphemes, since the reproduction of the rhythm predicted, significantly, the number of correctly written graphemes, as well as the use of alphabetic spelling.
			Study 2: 96 participants		
			Age range: 8 y. and 9 months (average age)		
Wang et al.[39]	Taiwan	Case-control	55 participants: 28 with dyslexia and 27 in control group.	Chinese character recognition, lexical tone perception, frequency discrimination and FM scan direction identification.	Children with developmental dyslexia, who use the Chinese language, performed significantly worse in all tasks.
			Age range: 9 y. (average age)		Poor auditory frequency processing may be associated with phonologically deficient Chinese developmental dyslexia.
Souza et al.[20]	Brazil	Pilot stage of the study Cross-sectional	22 participants	Auditory evaluation: meatoscopy, EOAT and, in case of “failure” result, tympanometry; TCLPP, MSV and MSNV tests, TPF and DPT.	The Simple temporal ordering auditory skills, as well as TCLPP result, showed normal results in most participants.
			Age range: 8-10 y.		The association of the reading competence with the temporal processing has not demonstrated statistical significance.
Vanvooren et al.[40]	Belgium	Longitudinal	87 participants: 44 with increased risk of dyslexia and 43 from families with normal reading.	Auditory temporal processing tasks: FM, RT and DI; speech perception in noise task; phonological awareness; RAN; knowledge of letters; standardized reading tests.	The speech perception in noise has proved to be the factor that most contributed to the later phonological consciousness and a predictor of reading mediated by the association with phonology.
			Age range: 5 y.		

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Barker et al.[41]	New Zealand	Longitudinal	32 participants: 15 good readers and 17 readers with bad performance. Age range: 9-11 y.	Feather Squadron System: evaluation of behavioral measures of BP; recording of auditory cortical evoked potentials (CAEPs) by speech.	The study found altered central auditory processing in poorly performing readers using Feather Squadron behavioral measures and speech evoked cortical potentials.
Johnson et al.[42]	United States	Longitudinal	108 participants, tested in two different moments: 75 with speech disorder and 33 from the control group. Age range: average age 5 y. and 6 months (time 1) and 8 y. and 3 months (time 2)	Grey Reading Oral Test; Basic Reading, Spelling and Reading Comprehension subtests of the Wechsler Test; phonological awareness; fast AP assessment through a three-condition auditory masking task.	The analysis indicated a top-down effect, such that the phonological awareness had a greater impact over time, than the inverse. Regressions indicated a lack of direct impact of rapid central auditory processing on reading ability. Additional hierarchical regressions examined how well the rapid central auditory processing predicted reading ability when accounting for phonological awareness and vocabulary.
Yalçinkaya et al.[43]	Turkey	Case-control	67 participants: 26 with TPAC and 41 from the control group. Age range: 7-8 y.	Observational Assessment Scale (ORS), composed of four categories: listening, speaking, reading and writing	It was concluded that for school children, the TPAC may lead to or be associated with difficulties in written language.
Dawes et al.[44]	United Kingdom	Case-control	139 participants: 22 with DPAC, 19 with dyslexia and 98 from the control group. Age range: 6-13 y.	Standardized PA test (SCAN-C or SCAN-A); TOWRE (assesses reading); OSCCI spelling test; temporal hearing task battery.	Auditory psychophysical performance correlated positively with performance in SCAN-C, but not with reading ability. There were no significant differences between the performance of the DPAC group and dyslexia and no evidence of specific temporal hearing impairment.
Dawes et al.[45]	United Kingdom	Case-control	44 participants: 25 with DPAC and 19 with dyslexia. Age range: 10 y. and 4 months (average age))	TOWRE (assesses reading); OSCCI spelling test; standardized PA test (SCAN-C and SCAN-A).	There were equally high levels of attention, reading and language problems in both groups. The follow-up evaluation suggested high levels of autistic characteristics, previously not recognized within the DPAC group.

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Ferguson et al.[46]	United Kingdom	Cohort	88 participants: 22 with DEL, 19 with DPA and 47 from the control group. Age range: 6-13 y.	QI, digit amplitude, repetition of meaningless words, phonological evaluation, reading, grammar, sentence and non-verbal intelligibility of VCV.	There was no difference between the performance of children with DEL and with DPA, and both groups had consistent and significantly lower performance compared to the children in the control group. Speech intelligibility, both in noise and silence, was not impaired in the DEL and DPA groups.
Billiet et al.[47]	United States	Cohort	30 participants: 10 with dyslexia and abnormal brain stem time (G1), 10 with dyslexia and normal brain stem time (G2), and 10 typical controls. Age range: 8-12 y.	Tonal audiometry and tympanometry, ABR test per click and tests with BioMARK; TDD, TPF, FC and DFBP tests.	All G2 participants met the diagnostic criteria for central auditory processing disorder, while only 4 G1 participants met the criteria.
Boets et al.[48]	Belgium	Longitudinal	62 participants: 16 dyslexics, 20 non-dyslexics with high family risk of dyslexia and 26 non-dyslexics with low family risk. Age range: (1st, 2nd and 3rd time): 5 y. and 6 months, 6 y. and 10 months, 8 y. and 4 months (average age).	FM, GIN, noise speech perception and categorical speech perception tests; phonological awareness tests; literacy tests, standardized spelling test and six reading tests.	These longitudinal data indicated that alterations in central auditory FM processing, speech perception, and phonological awareness were present together in kindergarten children who later developed dyslexia.
Miller et al.[49]	United States	Observational Cross-sectional	64 participants: 35 participants with DPA and 29 in therapy for language impairment. Age range: 10 y. and 1 month (average age).	Audiological evaluation (tonal audiometry, tympanometry and EOAPD); TPF; DPT; TDD and SSW; phonological memory; reading fluency; verbal operating memory.	There were no differences in means between children with and without clinical diagnosis of DPA. Differences in group means in reading fluency were observed for children classified as DPA/non DPA and differences in group means in repetition of non-words, spatial working memory and two PA tests were observed for children classified as DEL/non DEL.
Poelmans et al.[50]	Belgium	Case-control	58 participants: 13 with dyslexia, 25 with low risk with normal reading and 20 with high risk with normal reading. Age range: 11 y.	FM, RT, DI; Noise Perception of Words and Noise Perception of Senses tests; Phonological awareness.	Children with dyslexia had difficulties with slow-rate central dynamic auditory processing and speech perception in noise. These problems persisted until the sixth year.

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Messaoud-Galusi et al.[51]	United Kingdom	Case-control	113 participants: 62 with dyslexia and 51 average readers. Age range: 6 y. and 6 months - 13 y. and 7 months	Phonological Assessment Battery; Non-Spectral Repetition Child Test; TOWRE Word Reading Efficiency Test; experimental tests, used to assess speech perception in noise and silence (Synthetic Continuum, Identification Tasks, Discrimination Tasks, Words in Noise, Words in Noise in Connected Speech).	Children with dyslexia, on average, performed worse than average readers in the task of identifying synthetic syllables in the silent discrimination and intermediate category (but not when tested using an adaptive procedure). Speech perception did not correlate with pseudo-word reading or phonological processing - the main abilities related to dyslexia.
Vandewalle et al.[52]	Belgium	Longitudinal	32 participants: 8 with specific language disorder (LSD) and literacy delay, 10 with LSD and normal literacy and 14 with typical development. Age range: 6 y. and 3 months - 6 y. and 8 months	FM and gap detection between channels; speech-noise perception and categorical perception; phonological awareness, verbal short-term memory, RAN; standardized reading and spelling tests.	Both normal reading groups did not differ in terms of speech perception or central auditory processing. Speech perception was significantly related to reading and writing in grades 1 and 3, and had a unique predictive contribution to the growth of reading in the 3rd grade, even after controlling reading level, phonological ability, central auditory processing and oral language skills in the 1st grade.
Georgiou et al.[53]	Canada	Case-control	62 participants: 21 with dyslexia, 21 from the control group (chronological age) and 20 from the control group (reading ability). Age range: 8-11 y.	Discrimination of Amplitude Elevation Time and Simple Time of Auditory Reaction; Phonological Processing; Speed of Rapid Naming (Digits and Objects); Phonological Memory; Spelling Choice and Quick Test of Spelling; Fluency of Reading.	Children with dyslexia did not have central auditory processing deficits and did not perform worse than their controls, of reading ability in any of the cognitive processing measures used in the study.

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Chobert et al.[54]	France	Case-control	48 participants: 24 with normal reading and 24 with dyslexia. Age range: 9-11 y.	Alouette reading test, phonological awareness and reading strategy tests, electrophysiological recording (EEG and EOG); pre-attention processing of speech sounds using the MMN. The children were presented with a sequence of syllables that included patterns (the "ba" syllable) and deviations in vocal frequency, vowel duration, and voice onset time (VOT), which were near or far from the pattern (small and large deviations).	No differences were found between the groups for frequency deviations. While children with normal reading showed larger MMNs for large deviates in vowel duration and VOT, than for small deviates, no size deviation effect was found in children with dyslexia.
Zaidan et al.[55]	United States	Prospective case-control	61 participants: 31 with dyslexia and phonological awareness deficit (G1) and 30 with normal reading skills (G2). Age range: 8-9 y.	Tonal Audiometry and immittance, Phonological Abilities Profile and GIN test.	Children from G1 had longer GAP detection thresholds and lower GAP identification scores than children from G2, with significant differences between groups.
Johnson et al.[56]	Australia	Case-control	32 participants: 16 with dyslexia and 16 with normal reading. Age range: 8-12 y.	Reading proficiency and phonological awareness tests; regular, irregular and pseudo-word reading; tonal audiometry; Auditory responses were elicited, using two types of broadband noise lasting 500 ms, which resulted in the perception of a central noise and a lateralized tone. Diotic pitch stimuli were included to assess the possibility of binaural hearing loss in children with dyslexia.	The responses were strongly lateralized in children from the control group. Children with dyslexia showed significantly less lateralization of cortical auditory function and a different pattern of auditory lateralization development with age.
Grube et al.[57]	United Kingdom	Exploratory	201 participants: 28 with dyslexia and 173 with typical development. Age range: 11 y. (average age)	Decision of rhyme writing, spelling, word reading, pseudo-words reading; repetition of non-words (from the Working Memory Test for Children battery); inverted digit recall; auditory test (4 pitch perception tasks, 4 rhythm and time tasks and 4 timbre perception tests based on modulation).	The dyslexic group performed significantly worse in language, but not in auditory measures. There was a tendency to decrease the correlations between the processing of short sequences and language skills, contrasted by a significant increase in the correlation for the basic processing of a single sound, particularly in the domain of modulation.

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Steinbrink et al.[21]	Germany	Longitudinal	236 participants Age range: 5-7 y.	Audiometry Tonal Liminal; Rapid Auditory and Visual Temporal Processing; standardized tests of reading and writing.	It has been suggested that rapid central auditory processing skills have a causal influence on the development of literacy.
Ahmmed et al.[22]	United Kingdom	Cross-sectional	110 participants Age range: 6-11 y.	SCAN-C (low-redundancy monaural speech and dichotic listening tests); central multicenter auditory processing IMAP (retrograde masking, simultaneous masking, frequency discrimination, non-verbal intelligence, working memory, reading, attention alert and motor reaction time for auditory and visual stimuli).	The study identified a general central auditory processing factor, as well as two other cognitive factors, "operational memory and executive attention" and "processing speed and alert attention", to substantiate the deficits in children with suspected DPAC. Individuals with central auditory processing deficiencies, along with tests of the other two cognitive factors, can explain the co-occurrence of DPA and other disorders.
Hämäläinen et al.[58]	Finland	Case-control	37 participants: 11 with family history of dyslexia and 26 from the control group. Age range: 5-6 y.	Knowledge of the letters of the Finnish alphabet; phonological identification, (phonological processing task); RAN. Passive eccentric EEG experiment with sinusoidal sounds with changes in frequency, duration or intensity of sound.	Responses to standard stimuli showed a negative voltage shift in children at risk of reading problems compared to children in the control group. In addition, children at risk of reading problems had higher late discriminatory negativity (LDN) in the range of altered sound frequency than control children.
Rocha-Muniz et al.[59]	Brazil	Prospective case-control	75 participants: 25 with DEL, 25 with TPA and 25 from the control group. Age range: 6-12 y.	TFR, TDD and TPF.	The inter-group analysis showed that in all tests, children in the TPA and DEL groups performed significantly worse than the control group. In addition, the DEL group showed worse results than the TPA group.
Calcus et al.[60]	Belgium	Case-control	60 participants: 20 with phonological dyslexia, 20 from the control group by reading level and 20 from the control group by age. Age range: 7-11 y.	Evaluation of informational masking (IM) of complex sequences.	The performance of normal reading control of children increased throughout the experiment, reaching a significantly better level than dyslexics in the last blocks.

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Chart 1. Continued...

Author	Country	Design	Casuistic	Tools	Main findings of the study
Tomlin et al.[61]	Australia	Case-control	155 participants: 50 from the control group and 105 from the group referred for PA evaluation. Age range: 7-12 y.	TPF, TDD, GIN, MLD and LiSN-S; Reading Fluency (Wheldall Passage Reading Evaluation).	In the scores of the group referred for PA evaluation in the TDD, TPF tests, the results showed significantly lower cognitive abilities, in general, in children referred for PA evaluation, compared to the control group.
Murphy et al.[62]	Brazil	Experimental	58 participants, distributed in five groups: 11 (attention), 13 (memory), 12 (sensory), 13 (placebo) and 9 (control). Age range: 5-8 y.	The tests were applied to the five groups, before and after the training period with the Active Listening software. Visual digit spam tasks, sustained auditory attention, Brazilian Compressed Speech Test; Phonological Awareness Test, Isolated Word Reading Test.	All the trained groups, especially older children, showed significant learning in the trained task. In pre- and post-training measures, most groups showed improvements in the largest number of tasks.
Carroll et al.[23]	United Kingdom	Longitudinal	267 participants Age range: 6-8 y.	Sound of letters; frequent word reading; Phonological awareness; RAN; Verbal Short Term Memory; Central auditory processing (DEST Sound Order Test); word reading accuracy (British Scale of Skills Single Word Reading Test).	Short term verbal memory, phonological awareness, and rapid appointment were good predictors of later misreading. Deficit in visual search and central auditory processing were also present in a minority of poor readers.
Souza et al.[24]	Brazil	Cross-sectional	109 participants Age range: 7-10 y.	TCLPP, TDE and ASPA.	There was an association with statistical significance between the reading competence in words/ pseudowords and the children's school performance. However, there was no evidence of association, with statistical significance, between reading competence in words/pseudowords, sociodemographic variables and auditory skills.

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Most studies(23,32,42,43,45,46,51,54,60,62,63) have used tests that evaluate the temporal aspects of central auditory processing. There is an implicit importance in including tests that evaluate temporal processing, i.e., temporal ordering and resolution, in research and diagnosis protocols for children and adolescents with complaints or evidence of reading and writing changes.

However, some studies(10,28) have shown that participants with reading and writing difficulties(10) and dyslexia(28) also had worse performance in figure-background hearing ability. Another study(22) indicated that the auditory closing ability is commonly altered in children with suspected central auditory processing disorder, and that this disorder often coexists with others that are related to cognitive factors.

Cross-sectional and case-control designs were the most frequently used in the present review studies. It should be noted, however, that although the studies with both types of design are important, they show significant differences. The cross-sectional studies aim to address the association between risk factors and disease (outcome), involving a random sample of a population of interest. They have more weaknesses, since the variables are evaluated simultaneously, revealing a "picture" of the situation at the moment, and not allowing inference about the causality of the studied aspects. The case-control studies, in turn, intend to compare a group of cases (patients) with a control group (without the disease), in relation to the presence or absence of an exposure factor in the past. The limitation of this type of study is that the need to survey the past history of the participants may reveal biases of selection and information(65,66).

Four experimental studies(26,35,62,63) carried out auditory training in the study group, and there was a significant improvement in the results of the reevaluations.

In one of the studies(26), the authors used the software "Auditory temporal training with non-verbal and verbal stimuli with expanded speech" ("*Treinamento temporal auditivo com estímulos não verbais e verbais com fala expandida®*"), which contains verbal and non-verbal games based on the *Fast ForWord Language* auditory training program. The aim of the research was to check the reading performance and temporal aspects of hearing in children with reading difficulties after the auditory training. In addition to the basic audiological evaluation, the central auditory processing tests (Frequency Standard - Auditec, Duration Standard - Auditec and Gaps in Noise - GIN), the Reading Skills Evaluation (Reading and Writing Protocol) and the Phonological Awareness Test (PAT)(26) were carried out. In the study, two games were used for the training: "*Jogo do Caco*" (non-verbal) and "*Jogo do Papagaio*" (verbal)(26). The authors of this article(26) concluded that auditory training was effective in improving temporal and reading skills performance in children with reading difficulties.

Two other experimental studies(35,63) indicated that after the auditory training, the performance in auditory skills improved, both in the group with learning disability and in the group of school children without learning disability.

An experimental study(62) conducted training including attention, memory and auditory sensory tasks. The authors found that in all groups (attention group, memory group, sensory group, placebo group and control group) the participants demonstrated learning in the trained tasks. However, this learning was not transferred to language measures (reading and phonological awareness), since both the placebo group and the control group improved in the same way as the other trained groups.

CONCLUSION

Based on the articles analyzed in this review regarding the interface between central auditory processing and reading processes in children and adolescents, it is possible to conclude that there is an association between reading and auditory skills, since most participants with difficulties in reading skills will also have impaired performance in auditory skill tasks. The studies revealed that the most altered hearing skills were ordering and temporal resolution. However, some studies also revealed altered figure-background auditory skills for verbal sounds and auditory closure. Additionally, auditory training has been found to be effective in improving auditory skills performance, and may also be effective in improving reading skills.

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