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Literature Review

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Evaluation of central auditory processing in children affected by stroke: a systematic review of the literature

Avaliação do processamento auditivo central em crianças e adolescentes acometidos por acidente vascular cerebral: revisão sistemática da literatura

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ABSTRACT

Purpose: To identify studies that have addressed Central Auditory Processing (CAP), through electrophysiological and/or behavioral tests, in children and adolescents affected by Stroke. **Research strategy:** A search was conducted in July 2017, using the descriptors: "*stroke*", *auditory perception*", "*childhood*", "*child*" and "*evoked potentials, auditory"* in PubMed, Scopus and SciELO databases. **Selection criteria:** Articles written in English, Portuguese and Spanish, published until July 2017, without start date limitation. The articles should present a methodological approach that refers to the findings of central auditory processing assessment in children and adolescents diagnosed with stroke. **Results:** First, 15 studies were found, and three of them were selected because they met the inclusion criteria and were considered relevant for the sample of the present study. As none of the included studies used LLAEP in their audiological assessments, a second search was performed with the descriptors: "*stroke*" AND "*children*" AND "*evoked potentials, auditory*" in the same databases. A total of 36 papers were found with these descriptors but only one paper was selected, according to the established inclusion criteria. **Conclusion:** Few studies in the literature have assessed central auditory processing in children and adolescents with stroke. Nevertheless, the studies are important for diagnos and therap monitoring in this population.

Keywords: Stroke; Children; Auditory perception; Evoked potentials, auditory; Electrophysiology; Review

RESUMO

Objetivos: Identificar estudos que tenham abordado as avaliações do processamento auditivo central, eletrofisiológicas e/ou comportamentais, em crianças e adolescentes acometidos por acidente vascular cerebral. **Estratégia de pesquisa:** Conduziu-se uma busca no mês de julho de 2017, usando os descritores: *stroke*, *auditory perception*, *childhood*, *child*, *children* e *evoked potentials auditory* nas bases de dados PubMed, Scopus e SciELO. **Critérios de seleção:** Foram selecionados artigos em inglês e português, publicados até julho de 2017, sem limitação de data inicial. Os artigos deveriam apresentar abordagem metodológica que referisse achados da avaliação do processamento auditivo central, em crianças e adolescentes com diagnóstico de acidente vascular cerebral. **Resultados:** Inicialmente, foram encontrados 15 estudos, resultando na seleção de três artigos que atendiam aos critérios de inclusão e que foram considerados relevantes para a amostra deste estudo. Devido ao fato de que nenhum dos estudos incluídos tenha utilizado os potenciais evocados auditivos de longa latência em suas avaliações audiológicas, optou-se por realizar uma segunda busca, com os descritores: *stroke* AND *children* AND *evoked potentials, auditory*, nas mesmas bases de dados. Com estes descritores, obteve-se 36 artigos e, destes, apenas um artigo foi selecionado, de acordo com os critérios de inclusão estabelecidos. **Conclusão:** Foram verificados poucos estudos na literatura, que tenham avaliado o processamento auditivo central em crianças e adolescentes acometidos por acidente vascular cerebral. Não obstante, salienta-se a importância dos estudos encontrados para contribuição nos processos de diagnóstico e de monitoramento terapêutico dessa população.

Palavras-chave: Acidente vascular cerebral; Infância; Percepção auditiva; Potencial evocado auditivo; Eletrofisiologia; Revisão

Study carried out at Departamento de Saúde e Comunicação Humana, Universidade Federal do Rio Grande do Sul – UFRGS – Porto Alegre (RS), Brasil.
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INTRODUCTION

Cerebrovascular accidents (CVA) or strokes in children and adolescents are rare events, when compared with adults. However, they are extremely complex because they have severe complications and require a high degree of clinical suspicion for diagnosis, as initial signs and symptoms are not very specific; rather, they are similar to those of other neurological diseases[1,2].

Auditory system integrity is essential to ensure efficient acquisition of speech and learning of written language. Hearing is the main entry path for speech acquisition. Proper acquisition and development of language and speech depends on anatomical and physiological integrity of the peripheral and central auditory systems[3]. Children's difficulty in analyzing and interpreting sound patterns may be due to learning difficulties as a result of central auditory processing disorder (CAPD). Adequate diagnosis and appropriate therapeutic intervention require knowledge of communication disorders and their correlations.

Assessment of auditory abilities can occur through behavioral methods, e.g., testing central auditory processing (CAP) skills, or through electrophysiological tests, which reflects, in particular, the activity of the auditory pathway in response to stimuli, from the brainstem to the cortex, thus enabling the assessment of sequential information processing, immediate memory span and/or decision-making skills[4,5].

Auditory Evoked Potentials (AEP) are widely used to check and monitor changes in hearing after auditory training therapy. They are useful for diagnosing and monitoring neurophysiological changes in the central auditory pathway[6].

OBJECTIVE

Given the importance of research on auditory abilities in children and adolescents affected by stroke, the aim of this systematic review of the literature is to identify studies that assessed central auditory processing in this population, through both behavioral and electrophysiological tests, because there are still few studies on the subject. In this perspective, this review is relevant as it reports studies conducted with children and adolescents that were published in the scientific literature.

Research strategies

This is the main research question used in the present work: "*Are there publications about long-latency auditory evoked potentials (LLAEP) in children and adolescents diagnosed with stroke?*".

In order to find answers to this question, a search was performed for publications available in the databases PubMed, Scopus and SciELO in order to conduct a comprehensive and systematic review of the literature. The search included studies published until July 2017, without start date limitation.

The descriptors had been previously searched in the *Medical Subject Headings* (MeSH). All the possible combinations between the descriptors from the first search were used: *stroke, auditory perception, childhood, child, children and evoked potentials, auditory* and also those determined for the second search: *stroke AND children AND evoked potentials,* auditory. As no studies about this theme were found after the search, a second research question was formulated based on these descriptors: "*Which central auditory processing assessments, through both behavioral and electrophysiological tests, were performed in children and adolescents affected by stroke, and what were the results*?"

Selection criteria

The studies were selected according to the following inclusion criteria: publications until July 2017, without start date limitation, written in English, Portuguese and/or Spanish; original studies with children and adolescents affected by stroke, diagnosed through imaging exams or neurological assessment, submitted to at least one audiological evaluation with Long-Latency Auditory Evoked Potential (LLAEP) testing. Since there were no records of such assessments in children and adolescents with stroke, a decision was made to integrate and report, in the present study, other auditory processing assessments that were conducted with this population.

Studies were excluded when: i) they had an adult population (aged over 20 years); ii) stroke was not the only diagnosis; iii) they focused on associated syndromes; iv) they were systematic reviews of the literature, letters to the editor, case studies and studies without a direct link to the theme.

Chart 1 shows the information flow for the selection of the studies included in this systematic review, based on the method *Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement*[7].

Data analysis

First, two reviewers checked all the studies that had been identified by the combinations of the descriptors in the proposed databases. By reading the title and abstract, they selected the papers that met the previously determined eligibility criteria. After that, the full-text papers were retrieved. The main data of each paper were collected and added to a standardized table prepared for the present study. The following aspects were taken into account for analysis of the selected papers: year and place of publication, characteristic of the sample (number of participants and average age), variables assessed, if the subjects had been diagnosed with stroke through MRI analysis and/or neurological assessment and whether LLAEP had been assessed, or which assessments were used, in addition to results and conclusions.

The reviewers evaluated the full-text papers and selected them according to the previously determined eligibility criteria. The results of the analyses were compared between two raters and the classification of the criteria was reviewed at a meeting for consensus and comparison of differences.

The PEDro (Physiotherapy Evidence Database) scale was used to check the scientific evidence of the studies to help the researchers identify whether the clinical outcomes of the

Chart 1. Characteristics of reviewed studies

Name of paper	Authors	Country	Objective	Population	Sample	Age	Procedures
Central auditory processing outcome after stroke in children. Arq Neuro-Psiquiatr. 2014; 72(9):680-6.	Elias KMI,Oliveira CC, Airoldi MJ, Franco KMD, Rodrigues SD, Ciasca SM, Moura-Ribeiro MVL.	Brazil	Investigate central auditory processing skills in children and adolescents diagnosed with stroke	Children and adolescents diagnosed with stroke	Control Group: 23 Study Group: 23	7 - 16 years	1. Tonal audiometry; 2. Vocal audiometry; 3. Acoustic immittance measures; 04. WISC-III; 5. Bender Visual-Motor Gestalt Test; 6. School Performance Test; 7. Speech-in-Noise (SiN); 8. Dichotic Digits (DD); 9. (SSW); 10. Pitch Pattern Sequence (PPS); 11. Duration Pattern Sequence (DPS).
Stroke caused auditory attention deficits in children. Arq Neuro-Psiquiatr. 2012;71(1): 11-17.	Elias KMIF, Moura-Ribeiro MVL.	Brazil	Check selective attention ability in children and adolescents affected by stroke	Children and adolescents with stroke	Control Group: 13 Study Group: 13	7 - 17 years	1. Dichotic tests of binaural separation (non-verbal and consonant-vowel); 2. Staggered Spondaic Word Test (SSW).
Attention deficit disorders after stroke in childhood. Z Kinder Jugendpsychiatr Psychother. 2008; 36(6):419-26.	Eikelmann A, Petermann F, Daseking M.	Germany	Analyze the performance of auditory and visual attention in children and adolescents affected by stroke	Children and adolescents with stroke	Control Group: none Study Group: 78 children	5 - 10 years	1. Test of Attentional Performance (TAP); 2. Test of Attentional Performance for Children (KITAP); 03. Child Behavior Checklist (CBCL/4-18).
The functional organization of trial-related activity in lexical processing after early left hemispheric brain lesions: An event-related fMRI study. Brain Lang. 2010;114(2):135-46.	Fair DA, Choi AH, Dosenbach YB, Coalson RS, Miezin FM, Petersen SE, Schlaggar BL.	USA	Distinguish phonological and semantic processing in children with stroke.	Children with stroke	Control Group: 111 Study Group: 13	Children with stroke: aged less than 13 years; Control Group: 7 - 32 years	1. IQ Scale; 2. Event-related functional magnetic resonance imaging (fMRI); 3. Controlled and simple lexical processing tasks

Chart 2. Methodological rating assessed by the PEDro scale

	External validity (Max = 1)	Internal validity (Max = 8)	Interpretable Results (Max = 2)	Total Score (Max = 11)
Elias et al.[8]	1	2	2	5
Elias et al.[9]	1	2	2	5
Eikelmann et al.[10]	1	2	1	4
Fair et al.[22])	1	2	1	4

Subtitle: Max = Maximum

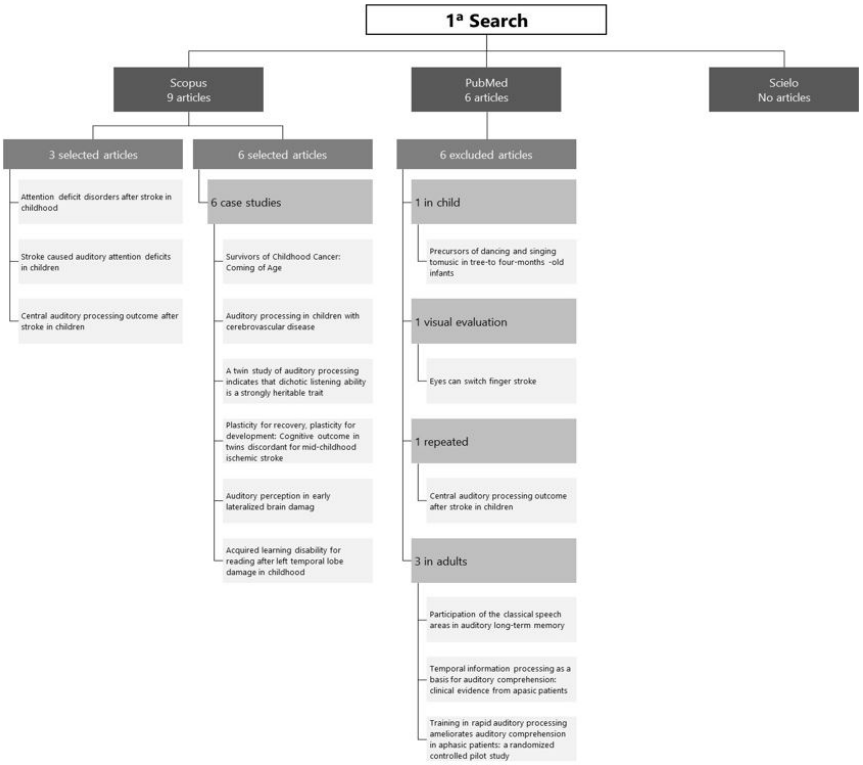

Figure 1. Flow diagram of the structure of research and selection of articles, in the first search

applied therapies met the established criteria. An analysis was made of the 11 items of the checklist, which investigate internal validity, external validity and the results that can be interpreted statistically. Chart 2 shows the methodological classification as assessed with the PEDro scale and the score of the papers in each item of the scale.

RESULTS

When the first three selected descriptors were inserted in each database for the present study, there was a total of 15 studies[8-21]. One study[8] was excluded because it was repeated in the search in PubMed, hence there were 14 studies left. None of these studies used long-latency auditory evoked potentials for evaluation in children or adolescents affected by stroke. For this reason, the previously selected descriptors had to be reconsidered. A second phase of the research took place, with new descriptors; again, no study used long-latency auditory evoked potentials to evaluate this population.

Three papers[8-10] were selected in the first search and one paper[22] in the second. All the studies that evaluated children diagnosed with stroke were read in full. Thus, only four papers were left[8-10,22]: three[8-10] from the Scopus database and one from the Scopus database in the second search[22]. Notably, no article was found in the SciELO database.

It is also noteworthy that none of the studies included assessment of LLAEP in children and adolescents affected by stroke. In addition, few studies assessed central auditory processing in this population. The papers that focused on children/adolescents and which were selected to be read in full were cross-sectional studies.

Figure 1 shows the process of selection of papers in the first search, using the descriptors *stroke, auditory perception* and *children*.

Figure 2 shows the process of selection of papers in the second search, with the descriptors *stroke, children* and *evoked potentials, auditory*.

Figure 3 shows that the number of papers found in the first search in MeSH *(stroke, children* and *auditory perception)* and in the second search in MeSH *(stroke, children* and *evoked potentials, auditory).*

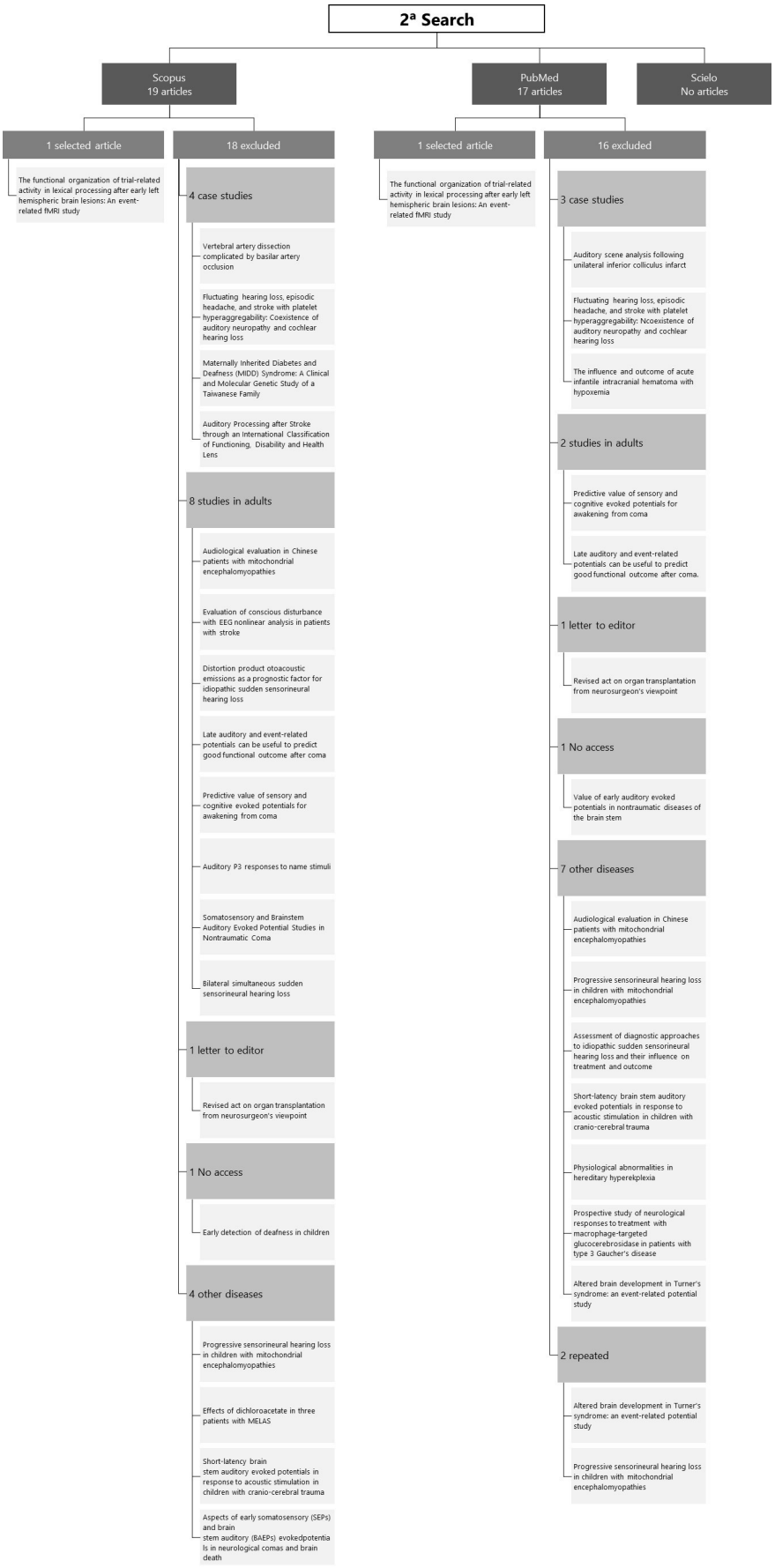

Figure 2. Flow diagram of the structure of research and selection of articles, in the second search

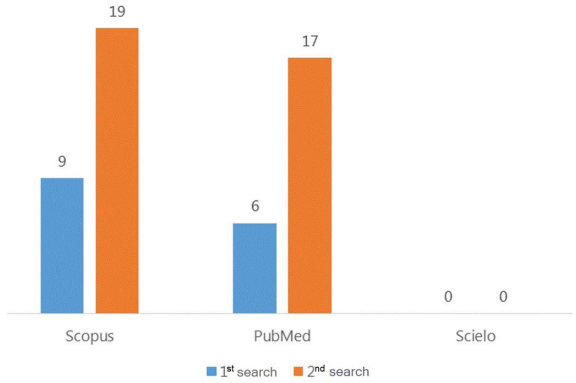

Figure 3. Comparison between the first and second searches in the database

DISCUSSION

The studies included in this review[8-10,22] assessed auditory processing in various ways: two studies[8.9] used Speech-in-noise Tests (SiN), the dichotic digits test (DD), the Staggered Spondaic Word test (SSW), pitch pattern sequence (PPS) and duration pattern sequence (DPS); another study[10] used sub-tests of the Test of Attentional Performance (TAP) and the Test of Attentional Performance for Children (KITAP) associated with a questionnaire to parents, namely, the Child Behavior Checklist (CBL 4-18)[10]; another study[22] used event-related functional magnetic resonance imaging (fRMI). All selected papers had been written in English, between 2008 and 2014; two studies were conducted in Brazil[8.9], one in Germany[10] and one in the United States[22].

In the first study[8], with 23 children and adolescents with unilateral arterial stroke and ages ranging between seven and 16 years, diagnosis was confirmed by clinical examination and neuroimaging, and magnetic resonance imaging (1.5T) was used as a reference to define the areas affected by the vascular lesion. For inclusion in the study group (SG), the criterion used by the authors was presence of resonance imaging and/or computed tomography scan, i.e., neuroimaging exams to confirm the impairment of the central auditory pathways and/or adjacent areas which consist of cortical and subcortical structures and interhemispheric connections. For this reason, the study group was compared with a control group (CG), composed of healthy right-handed children, whose age, sex and socioeconomic level were similar to those of children in the SG. All participants were assessed for peripheral auditory system, language, cognition and attention within the normality pattern. The speech-language assessment was based on standardized tests, using a screening process with spontaneous and semi-spontaneous themed images, during conversation. Auditory processing assessment was performed with audiologic tests (tonal audiometry, vocal audiometry, tympanometry and acoustic reflex testing (ipsilateral and contralateral). For neuropsychological assessment, the authors used the Wechsler Intelligence Scale for Children (WISC-III), the Bender Visual-Motor Gestalt Test and the School Performance Test. Exclusion criterion were: bilateral stroke, recurrent stroke episodes, sickle cell anemia, epilepsy and psychiatric disorders. Individuals were also excluded when they had language difficulties, hearing sensitivity to ossicular mobility in the middle ear, acoustic reflex responses and intelligence quotient (IQ) below 70. Auditory processing assessment used the following tests: Speech-in-Noise (SiN), dichotic digits (DD), staggered spondaic word test (SSW), pitch pattern sequence (PPS) and duration pattern sequence (DPS).

The filtered speech test was the most sensitive among monotic procedures for identification of impairment of auditory closure ability, while in dichotic tests, the GE presented difficulty in the two types of task, binaural integration and binaural separation. In the dichotic tests, the SG performed significantly worse than the CG, when both verbal and non-verbal stimuli were used.

Among the procedures that evaluate temporal processing, the duration pattern sequence test was more sensitive in identifying disorders in this skill. The children in the SG presented varying degrees of auditory competence; most of them had moderate impairment of auditory competence and lesion characteristics. Lesion characteristics, when analyzed alone, did not have a statistically significant effect on degree of auditory processing ability.

In the second selected study[9], carried out with 13 children and adolescents with stroke and ages between seven and 16 years and a control group (CG) with children at the same age, diagnosis was performed and confirmed by neuroimaging and neurological evaluation. All participants had normal levels of peripheral hearing, language and cognition, compatible with the tasks required by CAP tests. Auditory processing assessment occurred after a minimum period of six months after the stroke event and consisted of the application of four CAP tests: non-verbal dichotic, consonant-vowel, dichotic digits, and staggered spondaic word (SSW). Attentional performance differed between groups, and in the non-verbal test, there was a smaller number of identifications with the ear contralateral to the lesion and with undirected attention and difficulty in focusing attention on the directed steps. In the consonant-vowel test, there was a deficit in perceptual asymmetry and difficulty in focusing attention on the directed steps. In the digits and SSW tests, there were contralateral, ipsilateral and bilateral impairments, depending on lesion characteristics and task demand. The authors of this study concluded that children affected by stroke showed deficits in selective attention in the presence of simultaneous sources of verbal and non-verbal auditory information.

The objective of the third selected study[10] was to assess attentional performance of 78 children diagnosed with stroke, using sub-tests of the test of Attentional Performance (TAP) and the Test of Attentional Performance for Children (KITAP), in which children use two pathways during the application of the test (visual attention and auditory attention, simultaneously). Furthermore, the questionnaire *Child Behavior Checklist /4-18*(CBCL/4-18) was answered by the parents. It is used worldwide to identify mental health problems in children and adolescents. The results were categorized by age at the time of stroke, cerebral hemisphere and location affected. It was found that sex and age, at the time of stroke, as well as location of the cerebral lesion (cortical vs. subcortical) showed no significant effect. This impairment tends to occur more often in attention disorders after a stroke in the right hemisphere. Thus, if it reinforces the need for early diagnosis and effective treatment to prevent the development of comorbid diseases and learning difficulties.

In another selected study[22], carried out in a child population aged between five and 13 years old with right hemiparesis and perinatal damage in the left hemisphere, the results were

compared with those of the control group, composed of 111 right-handed individuals, with ages ranging between seven and 32 years. All individuals in the study were assessed by a pediatric neurologist, who complemented the evaluation with a detailed health questionnaire to assess typical development. Neuropsychological tests were also used to collect data on intellectual level and IQ scale. All individuals underwent event-related functional magnetic resonance imaging (fRMI). According to the authors of studies[23,24] about a set of controlled and simple lexical processing tasks (previously described in the literature), the objective of the test is to distinguish phonological processing from semantic processing. However, the absence of differences in robust functional neuroimaging findings, between the tasks, resulted in a breakdown strategy, as previously reported in other studies. Initially, the objective of the study was to resolve some significant methodological concerns when using fMRI to study the functional neuroanatomy of lexical processing in children with perinatal stroke. However, over the course of the study, the researchers realized that, when dealing with different brain lesion locations, known as mixed lesions (cortical and subcortical) and local lesions, the results, with each subject, were more consistent with the idea that functional organization, after left hemispheric lesion, is variable and depends very much on location, size and time of stroke. The authors concluded that there is a need for large samples of patients, in which the groups can be separated by identical or similar lesions and the same age. Variability in the etiology, start, size and location of the lesion, which are the main factors, makes it difficult to collect large and homogeneous samples of patients with stroke; however, it would be ideal for the quality of the study.

The present study has some limitations. There was a small number of scientific studies about this theme. Furthermore, the results found in this study were quite diverse because there were methodological variations in the reviewed studies, as evidenced by the analysis of results, which required a detailed discussion of each item. On the PEDro scale, few articles met the criteria of the checklist*;* therefore, the studies had a low overall score because there was no blinding, no concealed allocation and no random allocation of subjects to groups.

Only one study had no control group (CG)[10]. The other studies[8,9,22] had a common procedure: they made comparisons with a GC, with CAP studies[8.9] and with the same age range; however, the neuroimaging study[22] used a GC in which the age of participants was greater than in the study group (SG) (up to 32 years). Moreover, these studies focused on brain localization, topodiagnosis of stroke and laterality in children prior to the stroke event. Neuropsychological assessment was performed with the Wechsler Intelligence Scale for Children (WISC-III) in the studies on CAP[8.9] while the IQ scale was used in the neuroimaging study[22].

The analysis of the published papers showed that they used heterogeneous methods. No studies were found in the literature about the use of either auditory evoked potentials or long-latency evoked potentials for assessment of children and adolescents affected by stroke, despite the vast possibility of clinical application of these potentials in this population. Importantly, only two studies described findings for CAP in this population[9.10]. For this reason, both of them were described in this study, as a form of input for future research.

CONCLUSION

This review of the literature has shown the scarcity of studies on central auditory processing in children and adolescents affected by stroke, especially with electrophysiological assessments by long-latency auditory evoked potentials, as recommended in the guidelines published by the American Academy of Audiology[25]. However, the currently available studies are particularly important because they have contributed to research on central auditory processing skills and can provide further insights into the processes of assessment, differential diagnosis and therapy monitoring of this population.

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