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Review articles

Behavioral tests used to assess central auditory processing in children – an integrative literature review

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ABSTRACT

Purpose: to analyze the Brazilian bibliographic production, in the last decade, regarding the most used behavioral tests to assess central auditory processing in children.

Methods: an integrative literature review, whose research question was, "Which behavioral tests are most used to assess children's central auditory processing?". The following search strategy "(auditory processing) AND (behavioral tests) AND (children)", was used to consult the Oasisbr, VHL, and SciELO databases. Free-access studies, published in full text in national and international journals, in Brazilian Portuguese or English, with replicable methods, and whose descriptors and topics answered the research question, were selected. Reviews, opinion articles, administration reports, websites, policies with indicators, information systems, and repeated or duplicate publications, were excluded. Two researchers conducted the analysis, and the studies were classified as either feasible or unfeasible. Data were collected between September and November 2021 and organized in tables and spreadsheets developed in Microsoft Excel.

Literature Review: initially, 64 studies were located, but after applying the eligibility criteria, 28 publications remained, which were read in full text.

Conclusion: the Frequency Pattern Test, Dichotic Digits Test, Gaps in Noise Test, Speech-in-Noise Test, and Pediatric Speech Intelligibility were the most used behavioral tests to assess children's auditory processing.

Keywords: Child; Hearing Tests; Hearing; Auditory Perception; Hearing Disorders

A study conducted at Universidade Estadual Paulista "Júlio de Mesquita Filho" - Unesp – School of Philosophy and Sciences, Marília, São Paulo, Brazil.

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INTRODUCTION

Hearing is a complex sensory system involving mechanisms that go beyond simple sound transmission[1]. Studies have widely addressed central auditory processing (CAP), which is the person's capacity to analyze and process auditory information received, effectively and efficiently[1]. This process involves a series of auditory skills (sound detection, localization, and discrimination; recognition; temporal ordering; figure-ground for verbal and nonverbal sounds; auditory synthesis; binaural integration, interaction, and separation, auditory closure; and temporal pattern recognition). These skills enable the comprehension of acoustic stimuli that are picked up by the peripheral auditory system[1].

Disabilities in this process may lead to central auditory processing disorder (CAPD)[2], characterized by inefficient auditory skill performance, resulting in difficulties comprehending picked-up auditory stimuli[2]. CAPD is included in the International Statistical Classification of Diseases and Related Health Problems (ICD-10) as a possible diagnosis of hearing changes[2]. Authors have stated in research that deficits in this system cause comprehension, learning, and language difficulties[2-3]. Hence, it can be deduced that CAPD may coexist with other language disorders and neurological conditions or be mistaken for other diagnoses, due to its similarity with the patient's behavioral signs and symptoms[2-4].

Auditory skills are essential to children's adequate speech and language acquisition and development[4]. The earlier CAPD is detected in a child, the better the prognosis and therapeutic process[5-7]. Moreover, having a qualified professional identify and follow up on this disorder helps diminish its negative impacts on this population's learning to read and write[8], as such professionals use actions, strategies, and environmental changes to aid the process[8].

Souza et al.[9] and Amaral, Carvalho, and Colella-Santos[3] highlighted in their research that there are few methods to investigate CAP auditory skills and no gold-standard procedure to this end. However, there is great interest in making adequate assessments with quick and effective behavioral tests to detect CAPD, especially in schoolchildren. Effort has been made to find easily applicable procedures that quickly confirm diagnoses, encompassing all mechanisms in the central auditory system, with adequate interactivity to contribute to pediatric assessment. Studies like this review, which scale the tests most used to assess CAP in children, may bring great contributions, directing assessors in the analysis of auditory skills.

According to Sakai[10], CAP must be assessed by speech-language-hearing pathologists, who have the authority to decide which tests must be included in the diagnostic battery. However, Magalhães[1] has stated in her research that scholars recommend that the battery of CAP behavioral tests include at least one test to assess each of the following aspects: monaural and dichotic hearing, temporal ordering, temporal resolution, auditory discrimination, sound localization, competing sounds, degraded acoustic signals, and binaural interaction. Moreover, the child's age, cognitive and linguistic development, and health status, the order of the tests, and other factors that might interfere with the child's performance in the assessment must also be considered[1].

A method that has been used is the Simplified Auditory Processing Assessment, a behavioral test battery that assesses CAP with some advantages, such as its ease of access and application, low cost, and high effectiveness in assessing auditory skills[9]. It can be combined with questionnaires – such as the Scale of Auditory Behaviors (SAB) – that are available and validated to Brazilian Portuguese, addressing hearing behaviors that may indicate a risk for CAPD[2,3]. Magalhães[1] has pointed out in her study that there are standardized behavioral tests to screen children 7 to 12 years old. Nonetheless, adequate investigation can detect signs of changes in the auditory system maturation and, therefore, in its processing at even earlier ages.

Speech-language-hearing pathologists who work in this area must choose from the various existing CAP assessment tests. Thus, knowing the ones that are most used helps them select adequate batteries for each patient, especially in in-person clinical settings[1]. Research like this one may also help national recommendations of tests to be included in a CAP assessment battery. Thus, the following research question was raised: "Which behavioral tests are most used to assess children's CAP?". This study aimed to analyze the Brazilian bibliographic production in the last 10 years, addressing the most used behavioral tests to assess children's CAP.

METHODS

Research strategies

The researchers conducted an integrative literature review[11,12], which did not require its evaluation by the Human Research Ethics Committee.

The researchers first outlined the topic and research question that would be used in the research and included in the databases to search the items to be studied: "Which behavioral tests are most used to assess children's CAP?". They also used the PICO acronym, which stands for patient, intervention, comparison, and outcomes. Thus, they were designed as follows: the first element of the strategy (P) corresponded to children; the second (I), to behavioral tests; the third one (C) was not used in this review; and the fourth element (O) was represented by the frequency with which these tests are presented in the studies.

The period of publication was established from 2012 to 2021 – i.e., the review comprised studies with up to 10 years of publication. Then, the researchers defined the Boolean operator "AND" and the search strategy: "(auditory processing) AND (behavioral tests) AND (children)". The following databases were previously chosen: Oasisbr (Brazilian Portal of Open Access Publications and Scientific Data - http://www.ibict.br); VHL (Virtual Health Library - https://bvsalud.org/) – which encompasses the following databases: MEDLINE, Index Psicologia – Journals, and LILACS (Latin American and Caribbean Health Sciences Literature) –, and SciELO (Scientific Electronic Library Online - http://www.scielo.br). These databases comprise many publications in the area of health. However, no specific scale was used to evaluate the level of evidence of the studies selected for this review.

Eligibility Criteria

Study inclusion and exclusion criteria were defined as described in Table 1 to make the review as objective as possible.

Also, this research defined children as those aged 2 to 12 years.

Table 1. Study eligibility criteria

Variables	Inclusion	Exclusion
language	Portuguese and/or English	Other languages
Access	Free	Restricted or paid
Country	Brazil	Other countries
Year of publication	From 2012 to 2021	Before 2012
Indexed	Oasisbr, VHL, and SciELO	Other databases
Publication format	Published in full text	Only abstract or conference proceedings
Descriptors or keywords	Hearing Tests Child Hearing Auditory Perception Hearing Disorders	Studies that did not use any of these keywords; that used them but did not address the topic; or that did not answer the research question
Methodology	Clear, objective, and replicable	Not replicable
Journals	National or international, with the year and place of publication	Independent publication
Eligibility	Individual or institutional case reports, experience reports, qualifications, intervention proposals, theses, dissertations, senior writing projects, scientific studies, and quantitative and qualitative research	Reviews, opinion publications, administration reports, websites, policies with indicators, information systems, and repeated or duplicate publications

Captions: Oasisbr = Brazilian Portal of Open Access Publications and Scientific Data; VHL = Virtual Health Library; SciELO = Scientific Electronic Library Online;
Source: Developed by the author.

Data Analysis

After the analysis of selected studies, the results were organized, compiled, and tabulated on a Microsoft Excel spreadsheet. Both researchers analyzed and assessed the studies' eligibility by reading their titles and abstracts and considering the research inclusion and exclusion criteria. These studies were then classified as feasible or unfeasible, resulting in a chart that demonstrated them clearly and objectively. In the case of divergences, the study was examined more in depth until the researchers reached a consensus, aiming to minimize possible errors or biases. The data were collected between September and November 2021.

LITERATURE REVIEW

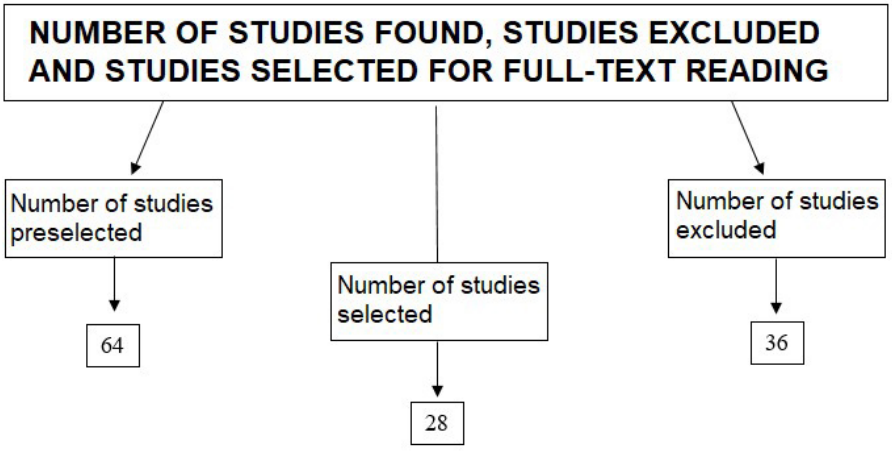
Altogether, 33 studies were found in Oasisbr, using the operators and year filter described above. In VHL, 21 studies were found, and in SciELO, 10 results were obtained for assessment. These studies were previously selected by analyzing their titles and abstracts and briefly scanning their content, as shown in Chart 1.

Chart 1. Number of studies found in the selected databases

Database		Number of studies found
Oasisbr		33
BVS	MEDLINE	04
	LILACS	16
	Index Psicologia – Journals	01
SciELO		10
TOTAL		64

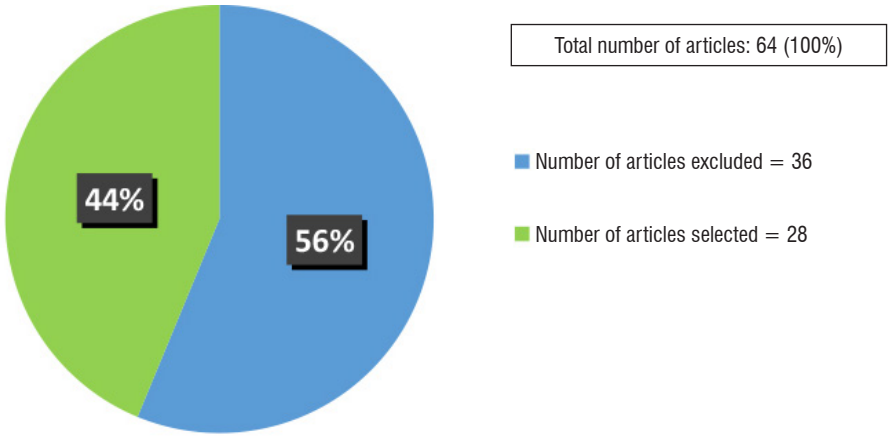
Captions: Oasisbr = Brazilian Portal of Open Access Publications and Scientific Data; VHL = Virtual Health Library; MEDLINE = Medical Literature Analysis and Retrieval System Online; LILACS = Latin American and Caribbean Health Sciences Literature; SciELO = Scientific Electronic Library Online; Source: Developed by the author.

Of the 64 preselected studies, one was eliminated for not being available for free access; 29 studies were excluded for being duplicates (master's dissertations or doctoral theses that were later published as scientific articles were read in their article version); one study was excluded for being an international publication; three were excluded for having the descriptors but not answering the research question; and two were excluded for being review studies. Thus, 28 studies were selected for full-text reading (identified with an S, for study, and numbered from 1 to 28), as shown in Figures 1 and 2.



Source: Developed by the author.

Figure 1. Flowchart of preselected studies



Source: Developed by the author.

Figure 2. Percentage chart of excluded and selected studies

The analysis results showed that eight of the 28 studies were conducted at the Universidade de São Paulo (S1, S4, S7, S9, S11, S12, S15, and S23); six at the Universidade Estadual de Campinas (S2, S8, S17, S19, S20, and S28); six at the Universidade Federal de Minas Gerais (S3, S5, and S24); one at the Universidade Federal do Sergipe (S6); one at the Universidade Federal do Rio Grande do Sul (S18); one at the Universidade Federal de Santa Maria (S10); two at the Universidade Federal de Santa Catarina (S13 and S14); four at the Universidade Estadual Paulista (S16, S21, S22, and S25); one at the Universidade do Minho, in Portugal, in partnership with the Universidade Federal de São Paulo (S26); and one at the Centro Universitário de Várzea Grande in partnership with the Universidade Federal de Mato Grosso (S27). This shows that most selected studies were carried out in either state or federal public universities.

Chart 2. Studies selected for the integrative literature review

Title	Objectives	Methodology	Tests
S1: The efficacy of an auditory temporal training program in children who present orthographic errors of the voiced-voiceless type[13]	To verify the effectiveness of a temporal auditory training program with activities adapted from Fast for Word to rehabilitate temporal auditory skills and reduce voiceless/voiced misspellings in children with this type of error.	Experimental study: 16 children aged 10 to 12 years, divided into a group that performed activities of the Temporal Auditory Training Program and a placebo group. They were assessed before and after the training with behavioral CAP measures and electrophysiological assessment.	FPT, GIN, PTT
S2: Audiological and behavior findings in children underwent a bilateral myringoplasty - a comparative study[14]	To analyze preoperative audiological assessment results in children submitted to surgical intervention to insert bilateral ventilation tubes; analyze the time the ventilation tubes remained; and assess CAP after the surgical intervention.	Experimental study: 79 students aged 8 to 12 years, divided into two groups, without a history of otitis media and with such history, submitted to surgery to insert bilateral ventilation tubes. All children underwent audiological and CAP assessments.	FPT, GIN, SSI
S3: Findings in behavioral and electrophysiological assessment of auditory processing[15]	To perform a descriptive analysis of the patients' CAP assessment performance and correlate the findings with the age, complaints, results, and behavioral and electrophysiological auditory assessments.	Observational study: 159 individuals submitted to CAP assessment, pure-tone thresholds audiometry, acoustic immittance, and electrophysiological auditory assessment.	FPT, GIN, MLD
S4: Audiological aspects of stuttering: behavioral and electrophysiological evidences[16]	To characterize the results of the GIN test and auditory evoked potentials with different complexity stimuli in stuttering children and typically developing children.	Cross-sectional, observational, prospective, descriptive study: 10 stuttering children (study group), aged 7 to 11 years, and their non-stuttering peers (control group) underwent audiological and electrophysiological auditory assessments.	GIN
S5: Temporal auditory aspects in children with poor school performance and associated factors[17]	To investigate auditory temporal aspects in children aged 7 to 12 years with poor school achievement and the association with behavioral aspects, health perception, school and health profile, and sociodemographic factors.	Cross-sectional, analytical, observational study: 89 children aged 7 to 12 years with poor school achievements. The parents were interviewed to collect data and the children, to investigate their self-perception of health, as well as CAP and auditory assessments.	SMTV, SMTNV, RGDT

Title	Objectives	Methodology	Tests
S6: Behavioral auditory processing assessment in five-year-old children[18]	To describe the characteristics of auditory processing in a cohort of 5-year-old children.	Cross-sectional exploratory study: 305 five-year-old children. The investigation addressed behavioral and socioeconomic aspects, previous prenatal, perinatal, and postnatal history, CAP assessment, and cochlear-palpebral reflex.	DNV, SSW, PSI, SLT, SIN, SMTV, SMTNV
S7: Behavioral, electroacoustic, and electrophysiological hearing assessment of malnourished children[19]	To characterize the findings of behavioral, electroacoustic, and electrophysiological hearing assessments in malnourished children and compare them to those obtained from same-age healthy children.	Cross-sectional descriptive study: 31 malnourished children (study group) and 34 healthy children (control group) aged 7 to 12 years, of both sexes, underwent audiological and CAP examinations.	DDT
S8: Central auditory nervous system assessment in children with a history of otitis media[20]	To assess the central auditory nervous system with behavioral and electrophysiological tests in children with a history of otitis media submitted to surgery to insert bilateral ventilation tubes and analyze the behavioral and electrophysiological assessment results after an auditory training program.	Cross-sectional experimental study: Individuals aged 8 to 14 years underwent complete audiological assessments and behavioral and electrophysiological assessments. Participants with abnormal results in two or more behavioral CAP assessment tests were invited to participate in an auditory training program and be reassessed afterward.	FPT, GIN, DCVT, SSI, DDT
S9: Performance of public and private school students in auditory processing, receptive vocabulary, and reading comprehension[21]	To characterize the performance of public and private school fifth graders in auditory processing, receptive vocabulary, and reading comprehension.	Cross-sectional, prospective, descriptive study: 34 fifth graders were assessed, and their parents and teachers answered a questionnaire on their language development, socioeconomic level, and school achievement. Auditory skills were assessed with behavioral tests.	FPT, PSI, DDT
S10: Effects of computerized auditory training in children with auditory processing disorder and typical and atypical phonological system[22]	To investigate the effects of computed auditory training through the analysis of the performance in behavioral tests and SAB in children with CAPD and typical and atypical phonological systems.	Comparative, cross-sectional, longitudinal, experimental study: 7 children with CAPD and typical phonological acquisition and 7 children with CAPD and atypical phonological acquisition. They were submitted to CAP behavioral assessment, Child Phonological Assessment, and therapeutic intervention.	DDT, NVDT, RGDT, PSI
S11: Efficacy of auditory training using the *Programa de Escuta no Ruído* (PER) software in students with auditory processing disorders and poor school performance [23]	To investigate the effectiveness of auditory training in this population, using the PER software, which, among the auditory processing skills, approaches hearing in noise.	Descriptive study: 18 children aged 8 to 10 years, of both sexes. All subjects participated in a preintervention assessment, intervention with placebo training, CAP reassessment, auditory training, and postintervention reassessment. Hence, subjects were their own controls.	FPT, SSW, SIN, PSI
S12: Early identification and intervention on language deficits and behavioral difficulties in early childhood education[24]	To detect and intervene in language and behavior difficulties in 3 to 4-year-old children.	Experimental study: the experimental group, with 84 children, was submitted to intervention to develop and improve language and manage problem behaviors with activities developed by a team with speech-language-hearing pathologists, psychologists, and psycho-pedagogues.	SAPA: SLT, SMTV, SMTNV
S13: The use of the dichotic digit test as a screening method[25]	To analyze DDT use as a screening method and compare its performance with a self-perception questionnaire and other CAP behavioral tests.	Cross-sectional retrospective study with medical record analysis: 66 medical records of children aged 8 to 11 years with and without DDT abnormal results. SAB and behavioral tests were used.	SMTV, PSI SMTNV, SLT, RGDT, SIN, DDT, FST, DPT
S14: The memory systems of children with (central) auditory disorder[26]	To investigate working memory, declarative memory, and procedural memory systems in children with CAPD and poor performance in phonological awareness assessment.	Experimental study: 30 children aged 9 to 10 years, divided into two groups 15 children each – one group with normal development, and the other with CAPD. The following tests were used: Phonological Awareness Sequential Assessment Instrument (CONFIAS test), E-Prime program 2.0, Working Memory Test Battery for Children, picture naming test, and morphosyntactic processing test.	GIN, PSI, DDT
S15: Auditory processing in children with dyslexia: electrophysiological and behavior evaluation[27]	To compare the performance of children with dyslexia as the experimental group with a control group in auditory processing tests and P300.	Experimental study: 22 dyslexic and 16 typically developing individuals, all of them submitted to CAP tests and P300 examination.	SIN, FPT, DDT
S16: (Central) auditory processing in schoolers in initial literacy grades[8]	To characterize and compare CAP behavioral tests in elementary school students in the test and retest stages and correlate the age and sex with the results of these tests.	Observational, longitudinal, prospective, analytical, cohort study: Group 1: 13 first graders; Group 2: 23 second graders. Audiological and CAP assessments took place at two different moments (test and retest), with a 6-month interval.	DDT, SLT SMTV, SMTNV, RGDT, PSI
S17: Auditory processing: behavioral and electrophysiological assessment in children with ADHD pre and post-auditory training[28]	To analyze the results of NVDT, DDT, SSI in Portuguese, DPT, GIN, and electrophysiological tests in children and adolescents diagnosed with ADHD before and after auditory training.	Cross-sectional, descriptive, experimental study: The study group had 14 subjects diagnosed with ADHD, aged 8 to 14 years. Only six of them underwent auditory training and were reassessed afterward. Study group data were compared with a control group.	DDT, DPT, NVDT, SSI, RGDT, GIN, FPT

Title	Objectives	Methodology	Tests
S18: Central auditory processing: behavioral and electrophysiological assessment of children and adolescents diagnosed with stroke[29]	To analyze the findings of electrophysiological and behavioral CAP assessments in children and adolescents diagnosed with a stroke and investigate possible associations with the type and localization of the stroke and age.	Cross-sectional comparative study: Individuals 7 to 18 years, divided into two groups, with and without a diagnosis of stroke. The assessment had the following procedures: medical history survey, basic audiological assessment, behavioral CAPD assessment, and electrophysiological assessment.	SSI, MLD, DCVT, PSI, DDT, FPT, GIN
S19: Central auditory processing outcome after stroke in children[30]	To investigate CAP skills in children with a unilateral stroke and whether the affected cerebral hemisphere influenced the auditory competence.	Comparative study: 23 children aged 7 to 16 years with a stroke had their CAP assessed, and the results were compared with those of control children.	FPT, DDT, SSW, DPT, SIN
S20: Central auditory processing in children with dysphonia: behavioral and electrophysiological assessment[31]	To analyze CAP assessment results obtained with behavioral and electrophysiological tests in children with dysphonia.	Cross-sectional comparative study: 16 children aged 8 to 11 years with and without dysphonia. Procedures used: medical history survey, voice recording, auditory-perceptual evaluation of voice, otoscopy, basic audiological assessment, CAP assessment, and electrophysiological tests.	DDT, SLT, SSI, SMTV, SMTNV, NVDT, GIN, FPT
S21: Processamento auditivo comportamental e eletrofisiológico em crianças com Transtorno de *Déficit* de Atenção com Hiperatividade (TDAH)[32]	To compare and correlate the findings of behavioral and electrophysiological assessment of the auditory processing of children with and without ADHD.	Comparative study: 30 children aged 8 to 12 years – 15 without ADHD who were not undergoing speech-language-hearing intervention and 15 with ADHD. Assessment procedures included electrophysiological and CAP tests.	FPT, DPT
S22: Processamento auditivo em crianças com transtorno de aprendizagem e dislexia[33]	To describe and compare the performance of children in CAP behavioral tests, describe the SAB scores, and verify the degree of agreement between the CAP assessment and SAB.	Retrospective analytical study: Analysis of electronic records of 60 children aged 9 to 12 years, divided into groups with and without a diagnosis of learning disorder. CAP assessment data were analyzed.	PSI, FPT, MLD, SSW, SIN, RGDT
S23: Auditory processing in children and adolescents in situations of risk and vulnerability[34]	To investigate aspects related to CAP with ABR tests and behavioral CAP assessments in homeless children compared with a control group.	Comparative study: CAP tests were applied to 27 individuals aged 7 to 16 years. ABR was also used to investigate the integrity of the auditory pathway.	DDT, NVDT, SMTV, SMTNV, SIN, PSI
S24: Quality of life of children with poor school performance: association with hearing abilities and behavioral issues[35]	To investigate the quality of life of children aged 7 to 12 years with poor school achievements and the associations with behavioral characteristics and auditory skills.	Cross-sectional observational study: Children aged 7 to 12 years were interviewed with their parents. The Quality-of-Life Assessment Scale and audiological and CAP assessments were also applied.	DPT, RGDT, SLT, SMTV, SMTNV, DDT
S25: Relationship between auditory evoked potentials and middle latency auditory processing disorder: cases study[36]	To analyze middle-latency auditory evoked potentials in two patients with auditory processing disorder and relate objective and behavioral measures.	Descriptive analytical case studies: Two patients (12 and 17 years old) were submitted to a medical history survey, external auditory meatus inspection, audiological assessment, and middle-latency auditory evoked potential assessment.	DDT, FST, SSW, SMTV, SMTNV, SIN, PSI
S26: Scale of Auditory Behaviors and auditory behavior tests for auditory processing assessment in Portuguese children[37]	To investigate Portuguese children's auditory skills and verify whether they are correlated with SAB scores.	Observational study: 51 children were submitted to basic audiological and CAP assessments. The parents filled out SAB adapted to European Portuguese. The study calculated the Pearson correlation coefficient values between the questionnaire and CAP test results.	DPT, SLT, SMTV, DDT, SMTNV, SIN, HDDT, GIN
S27: Home auditory training for children with impairment hearing due to cleft lip and palate[38]	To verify the impact of auditory training at home conducted by the parents for 30 days and its contribution to better CAP performance in children with auditory changes due to cleft lip and palate.	Case study: three children above 7 years old underwent basic audiological assessment and behavioral and electrophysiological tests. The parents/guardians answered a questionnaire to verify auditory and attentional behaviors.	SIN, PSI, DDT, FPT, NVDT, SLT, SMTV, SMTNV, SAAAT.
S28: Auditory training in children with a history of otitis media undergone ventilation tube placement[39]	To assess the effectiveness of auditory training in children and adolescents with a history of otitis media.	Cross-sectional, prospective, experimental study: 38 subjects submitted to peripheral auditory assessment and CAP assessment. The auditory training and visual training programs were the same for all participants, using activities taken from a website.	FPT, GIN, DDT, DCVT, SSI

Captions: CAP = central auditory processing, CAPD = central auditory processing disorder, FPT = Frequency Pattern Tests, GIN = Gaps in Noise, PTT = Progressive Temporal Test, DDT = Dichotic Digits Test, NVDT = Nonverbal Dichotic Test, SSI = Synthetic Sentence Identification, MLD = Masking Level Difference, SIN = Speech-in-Noise Test, SMTV = sequential memory test for verbal sounds, SMTNV = sequential memory test for nonverbal sounds, RGDT = Random Gap Detection Test, SSW = Staggered Spondaic Word, PSI = Pediatric Speech Intelligibility, SLT = Sound Localization Test, DCVT = dichotic consonant-vowel test, FST = Filtered Speech Test, DPT = Duration Pattern Test, HDDT = Harmonic Pattern Dichotic Digits Test, SAAAT = Sustained Auditory Attention Ability Test, SAB = Scale of Auditory Behaviors, PER = Hearing in Noise Program, ABR = auditory brainstem response, FPT = Frequency Pattern Test, ADHD = attention-deficit/hyperactivity disorder, CONFIAS = Phonological Awareness Sequential Assessment Instrument; Source: developed by the author.

Even though the research focused on children, it found that some studies analyzed in it included adolescents and adults in their samples[28,30,34,39]. Also, studies[8,13,16] demonstrated that the behavioral tests effectively assess CAP before and after interventions.

According to Berticelli[29], adequate auditory skill assessments must consider the patients' clinical history and select a test battery that assesses their auditory difficulties. The authors of various reviewed studies assessed CAP in participants with different clinical diagnoses using various test batteries[16,19,27,30,31,38]. For instance, Pires[13] pointed out that these tests are often used to assess CAP in populations with some difficulty or diagnosed change in oral and written language, who normally perform worse in tests than typical children.

Various studies in this review demonstrated statistically significant differences regarding the ears in dichotic tests, in which the right ears performed better in CAP assessment tests[8,14,20,26,28-29]. According to Sartori[8], this difference is due to the corpus callosum immaturity, while Menezes[33] explains this difference by the brain dominance effect.

Answering this review's research question, the following behavioral tests were the most used to assess CAP in children: Dichotic Digits Test (DDT – 64.28%), Frequency Pattern Test (FPT – 53.57%), Pediatric Speech Intelligibility (PSI – 42.45%), Gaps in Noise (GIN – 39.28%), and Speech-in-Noise Test (SIN – 35.71%). This corroborated some statements by Romero, Sorci, and Frizzo[36], whose study pointed out that in Brazil some of the most used tests are DDT, Filtered Speech Tests (FST) and SIN, Staggered Spondaic Word (SSW), PSI, FPT, Duration Pattern Test (DPT), and Synthetic Sentence Identification (SSI)[30,34,39].

Seven of the studies that cited FPT (S1, S2, S15, S19, S21, S22, and S27) tested the skill binaurally, and three (S9, S17, and S28) did so monoaurally in sequence. As for GIN, nine of the studies (S1, S2, S3, S4, S8, S17, S20, S26, and S28) tested monaurally in sequence. The other studies did not specify how they applied the tests.

Some other behavioral tests were used or cited in further detail to assess CAP in the analyzed studies, as follows: sequential memory test for verbal sounds and sequential memory test for nonverbal sounds (SMTV and SMTNV – both with 39.28%), Sound Localization Test (SLT – 28.57%), Random Gap Detection Test (RGDT – 25%), DPT (21.42%), SSW (17.85%), Nonverbal Dichotic Test (NVDT – 17.85%), SSI (17.85%), Masking Level Difference (MLD – 10.71%), dichotic consonant-vowel test (DCVT – 10.71%), FST (7.14%), Progressive Temporal Test (PTT – 3,57%), Harmonic Pattern Dichotic Digits Test (HDDT – 3.57%), and Sustained Auditory Attention Ability Test (SAAAT – 3.57%). However, they occurred less often in the studied literature[13,25,28,35,37].

Nalom[21] describes FPT – which Oliveira[27] stated is easy to apply – to assess the temporal ordering skill. This test presents sounds at different low and high frequencies to be discriminated and named. Pires[13] used FPT, GIN, and PTT to assess temporal processing in their subjects. The author highlighted that using symbolic association between sounds and linguistic and nonlinguistic symbols in auditory training can improve test performance in CAP temporal pattern assessment. Pires also pointed out that tests like FPT can assess other higher executive functions, such as memory and attention. The study by Romero[32] indicates authors who suppose that FPT and DPT assess different auditory processes but the same skill and that the former test is less sensitive than the latter.

DDT aims to recognize verbal sounds in dichotic hearing, encompassing both binaural integration and binaural separation[14,19,25]. It assesses the figure-ground skill for linguistic sounds, in which two digits are presented simultaneously to both ears[19,31]. DDT can be useful in basic CAP screening because it is quick and easy to apply, according to Almeida[19]. The author also informs that this test can detect cortical and brainstem lesions quite effectively. Bresola[25] states that DDT greatly contributed to detecting CAPD in patients, receiving recommendations from national forums. Researchers also indicate that international studies report DDT as an important tool for screening hearing disabilities, especially when combined with other instruments, such as questionnaires and scales[8]. Almeida[19] also highlights that further studies on DDT are needed, using the performance in this task as an inclusion criterion, as few reports demonstrate this test as useful for screening, besides its low performance as a variable associated with environmental factors.

The study by Gonçalves[16] reports that GIN assesses temporal resolution by detecting silent gaps in noise, with interruptions ranging from 2 to 20 milliseconds. The author's findings report that research has demonstrated that this test is greatly useful in assessing temporal resolution skills in children and confirming temporal processing deficits. The author also stated that GIN had high test-retest reliability and good sensitivity and specificity indices.

Pires[13] assessed auditory skills in children with learning difficulties and found that GIN was the test in which participants performed best, with results near or within normal standards. This finding is not necessarily related to the effectiveness of the test, but it can indicate that this auditory skill remains unaltered in some cases in this population, as this task requires less from the cognitive domains and depends on easier executions. Moreover, adequate stimulation can further improve the test results.

The study by Berticelli[29] presented some advantages of applying GIN, as it is easy to administer and demonstrates the early maturation of the temporal resolution skill. However, the author reported a lack of publications using this test to assess specific pediatric populations (e.g., children with a stroke or stuttering) with monoaural stimulation, which could help perceive unilateral changes.

According to Brasil[23] and Oliveira[27], SIN is a monotic listening test that presents 25 words to each ear to assess auditory closure. Its task is easy to apply, especially because it does not require the child's reading. Both SIN and FST, considered low-redundancy monaural tests, are suggestions included in the national recommendation of a minimum behavioral test battery to assess CAP. They have test tracks, which help understand the order in which they should be performed, and the decision on which test to use may depend on each case, at the examiner's discretion, according to what test is better for each child.

SSW assesses figure-ground auditory skills for verbal sounds and temporal ordering. It has 40 dichotic hearing items, in which individuals repeat words in the same order they are presented.

SSI and PSI assess figure-ground for verbal sounds and the association of auditory and visual stimuli. The tasks in both tests involve the recognition of verbal sounds (with the presentation of sentences and a story as the competing message) in monotic[31,39] or dichotic hearing. SSI must be applied to literate children because it requires reading competency to respond to the hearing task.

Reading and writing skills are known to be closely related to verbal memory. Hence, they are essential to perform complex cognitive functions, such as the reasoning capacity to solve problems. Santos[18] cites in her paper that SMTNV and SMTV are relevant to assessing short-term memory (especially in children) and simple temporal ordering skills.

RGDT assesses temporal resolution by detecting silent intervals in pure tone[22]. It requires more complex tasks, which may be a factor that discourages some children when performing it. Thus, Sartori[8] suggests applying RGDT in children above 7 years old, given the maturation of the central nervous system.

Rezende[17] stated that children may improve their performance in SMTNV, SMTV, and RGDT as they grow older, especially between 8 and 10 years old[31].

NVDT is useful to assess the physiological mechanism of selective attention and the figure-ground auditory skill for nonverbal sounds. This test presents six nonverbal sounds, presented in simultaneous pairs[22]. Melo[22] points out the RGDT, NVDT, and PSI are CAP assessment tests relevant to speech-language-hearing pathologists who want to research various processes, especially in children whose phonological development is unknown, as verbal communication changes do not interfere with the results of these tasks[8,15].

Berticelli[29] stated that MLD is the most used behavioral test to assess binaural interaction skills in CAP. It presents narrowband noise in the presence of pure tones and is easy to apply, as other tests described here.

As for SLT, Santos[18] reports that it aims to assess binaural interaction and sound source discrimination with no visual cues in five different directions. The participant is expected to locate four of the five directions presented.

DPT also assesses temporal ordering. It presents 60 pure tones, whose duration must be identified and sequenced by the subject – i.e., they must determine whether the stimulus was long or short[37].

Even though only Pires[13] comments on PTT, she informs that it can help assess the perception and processing of rapid temporal characteristics, even in children who have already been diagnosed with language changes. Pires[13] also pointed out that further research must address the theory of rapid temporal processing, using PTT.

Sartori[8] stated that some scholars questioned the reliability of auditory skill assessment tests because the performance of the individuals being assessed can be influenced by factors such as age, auditory experience, cognitive competencies, and so forth.

Lastly, as Bresola[25] recalls, few publications indicate a screening method sensitive to CAP changes. Furthermore, Sartori[8] cited the lack of epidemiological studies on CAP in the population aged 6 and 7 years. Pires[26] stated that more studies are necessary to reliably

understand the interaction of bottom-up and top-down processes in behavioral tests that assess CAP, as well as research that associates functional neuroimaging with CAP skills assessment using behavioral tests.

The probable limitations of this systematic review include the non-standardization of some variables investigated in the studies and the lack of an instrument to assess the level of evidence of the selected studies. Moreover, the combination of various studies may interfere with the rigor and precision of data, which can influence the interpretation of results. Lastly, the restriction on languages in the search for publications may have also posed some limitations to this review.

CONCLUSION

As previously pointed out in this study, behavioral tests have been widely used to assess CAP in various age ranges, especially in 4-year and older children[31]. FPT, DDT, GIN, SIN, and PSI were the most used behavioral tests in the studies addressed in this literature review to assess CAP in children.

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AMFA: conceptualization, formal analysis, investigation, methodology, visualization, and writing – original draft.

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