Literature Review

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The use of technology in the rehabilitation of central auditory processing disorder: a scoping review

Uso da tecnologia na reabilitação do transtorno do processamento auditivo central: uma revisão de escopo

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ABSTRACT

Purpose: To present scientific evidence related to the use of technology in the rehabilitation of central auditory processing disorder. **Research strategy:** The review was structured based on the international guidelines (PRISMA-ScR). PCC (Population, Concept, and Context) strategy was used to define the research question and inclusion criteria. Population: individuals with central auditory processing disorder; Concept: hearing rehabilitation program; Context: use of technology. **Selection criteria:** Included studies focused on individuals diagnosed with CAPD. They addressed auditory rehabilitation through technologies, such as auditory training programs, software, or other technological tools. Only clinical and intervention between 2019 and 2025 were considered. Articles needed to be available in English, Portuguese, or Spanish. **Results:** The initial search retrieved a total of 478 articles, After removing 5 duplicate articles, 473 records remained for the subsequent stage. During the selection phase, 239 records were excluded after analyzing the titles, and subsequently, 89 records were eliminated after reading the abstracts only 8 studies remained after exclusion based on the criteria. **Conclusion:** Technologies are emerging as effective tools for enhancing the auditory rehabilitation process, promoting neural plasticity, and improving central auditory skills. The auditory training programs, software, and applications analyzed show positive results in most studies, demonstrating their ability to adapt to users' specific needs and promote improvement in auditory performance.

Keywords: Information technology; Auditory perception; Acoustic stimulation; Program; Auditory perceptual disorders

RESUMO

Objetivo: Analisar evidências científicas sobre o uso da tecnologia na reabilitação do transtorno do processamento auditivo central (TPAC) e identificar as ferramentas tecnológicas utilizadas no treinamento auditivo. **Estratégia de pesquisa:** Trata-se de um estudo exploratório e descritivo, com abordagem qualitativa, fundamentada em uma pesquisa de revisão de escopo nas diretrizes do *Preferred Reporting Items for Systematic Reviews and Meta-Analyses - extension for Scoping Reviews*. A busca foi conduzida nas bases SciELO, PubMed, Scopus, LILACS, Cochrane Library, Open Grey e Google Scholar, com data de publicação entre 2019 e 2025, em inglês, português e espanhol. Os descritores foram selecionados conforme os termos MeSH/DeCS. **Critérios de seleção:** Os critérios de elegibilidade foram definidos por meio do formato PCC (Participante, Conceito, Contexto). A elegibilidade para o estudo foi caracterizada em: Participante - indivíduos com TPAC; Conceito - programa de reabilitação auditiva; Contexto: audição e tecnologia. Com base nos tópicos do PCC e nos objetivos do estudo, formulou-se a pergunta de pesquisa: "De que forma a tecnologia tem sido empregada na reabilitação de indivíduos com TPAC?". **Resultados:** Inicialmente, foram identificados 478 artigos, com exclusão de 348 após triagem, resultando em 13 elegíveis, dos quais, 9 foram incluídos na análise final. As intervenções analisadas incluíram *softwares* de treinamento auditivo, programas estruturados e terapias informais com CDs, todas voltadas à melhoria das habilidades auditivas centrais. **Conclusão:** Os achados indicam que a utilização de recursos tecnológicos constitui uma estratégia eficaz na reabilitação do TPAC, proporcionando intervenções mais dinâmicas e individualizadas. Evidencia-se, contudo, a necessidade de investigações que avaliem os efeitos em longo prazo e favoreçam a integração desses recursos com protocolos convencionais de reabilitação auditiva.

Palavras-chave: Informática médica; Percepção auditiva; Estimulação acústica; Programa; Transtorno de percepção auditiva

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INTRODUCTION

The central auditory processing (CAP) refers to the efficiency and effectiveness of the central nervous system in utilizing auditory information[1,2]. After being detected by the inner ear, sound undergoes physiological and cognitive processes to be decoded and understood. It is a mental activity, that is, a brain function, and therefore cannot be studied as a unitary phenomenon, but rather as a multidimensional response to auditory stimuli[3]. The CAP encompasses several central auditory skills that are fundamental for communication and cognitive development[4]. These skills include sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal and binaural aspects of hearing, figure-ground, and auditory closure[5].

The difficulty processing auditory information characterizes central auditory processing disorder (CAPD)[6-8], defined as a neurobiological change or a limitation in the reception, analysis, and processing of information received through the auditory pathway. Individuals with CAPD have difficulty locating, discriminating, recognizing, memorizing, and understanding speech, even with normal hearing thresholds and other preserved cognitive functions[9].

Therefore, auditory training consists of a set of acoustic conditions and tasks designed to promote neuronal reorganization of the auditory system and its connections with other related sensory systems, resulting in the improvement of previously altered abilities[10]. This process aims to modify both the neural basis and auditory behaviors, providing significant benefits to the performance of individuals with CAPD. One of the foundations of auditory training is the promotion of central nervous system plasticity, defined as the capacity for continuous modification in response to intense auditory stimulation. Training activities aim to optimize this plasticity through specific exercises that involve the use of central auditory abilities with different sound parameters of frequency and intensity. These activities may include tasks of sound pattern identification, sound discrimination in background noise, and activities for auditory memory.

Consequently, the use of new technologies has proven effective in aiding auditory training, making the rehabilitation process more dynamic and engaging with innovative tools and methods that provide functional reorganization of the brain and accessibility to auditory rehabilitation. Such technologies promote the development of neural connections, minimizing the functional consequences of changes in auditory abilities. With continued technological advancement, auditory rehabilitation approaches tend to become increasingly adaptable to individual needs, significantly improving the quality of life of patients with CAPD.

Technological tools allow for detailed and accurate assessments of individuals' hearing abilities, enabling the creation of personalized training programs. Auditory training software, apps, and platforms can automatically adjust the difficulty level based on the user's performance, ensuring a constant and progressive challenge. These features allow users to practice anywhere and at any time, encouraging adherence and increasing motivation.

Given the increasing use of technological resources in clinical and educational settings, it is crucial to investigate how these technologies are being applied in auditory training for CAPD. Available information on the types of tools used, application methods, intervention time, and core auditory skills covered remains poorly systematized. Therefore, the need for further research analyzing these variables becomes evident, aiming to understand the most commonly used strategies, identify knowledge gaps, and thus guide the development of more effective and personalized rehabilitation programs.

PURPOSE

Present scientific evidence related to the use of technology in the rehabilitation of central auditory processing disorder and identify the types of technological tools used in auditory training.

RESEARCH STRATEGY

The review was structured based on the international guidelines "Preferred Reporting Items for Systematic reviews and Meta-Analyses - Extension for Scoping Reviews" (PRISMA-ScR), registered with the International Prospective Register of Systematic Reviews (PROSPERO) under CRD420251076757. The PCC (Population, Concept, and Context) strategy was used to define the research question and inclusion criteria. The main elements guiding the process included:

- Population: individuals with central auditory processing disorder with thresholds within the normal range, without the need to specify age range and comorbidity;
- Concept: hearing rehabilitation program;
- Context: use of technological resources, such as software, applications, digital platforms, and electronic devices for auditory training.

Considering the main topics of the PCC strategy and the objectives of the study, the research question formulated was: "How has technology been used as a resource for the rehabilitation of people with CAPD?"

The electronic search was conducted in May 2024 in national and international databases, without using software to carry out the reviews: PubMed/MEDLINE, LILAC/BVS, SciELO, Scopus, Cochrane Library, and with an additional search of the gray literature in Google Scholar and Open Grey. A search of the references of the selected articles was also conducted. Search strategies were constructed using indexed and non-indexed terms related to the elements of the PCC strategy. Combinations of the following descriptors were used: PubMed/MEDLINE - ("Information Technology") AND ("Auditory Perception") AND ("Acoustic Stimulation") AND ("Program") AND ("Auditory Perceptual Disorders"); LILACS - ("Auditory Perception") AND ("Acoustic Stimulation") AND ("Information Technology") AND ("Program") AND ("Auditory Perceptual Disorders") AND ("Auditory Perception") AND ("Acoustic Stimulation") AND ("Telerehabilitation") AND ("Auditory Perception Disorders"); Scopus - ("Auditory Perception") AND ("Acoustic Stimulation") AND ("Telerehabilitation" AND ("Auditory Perception Disorders") AND ("Program") AND ("Auditory Perception") AND ("Information Technology") AND ("Acoustic Stimulation") AND ("Auditory Perceptual Disorders"); Cochrane Library - ("Auditory Perceptual Disorders") AND ("Acoustic Stimulation") AND ("Program") AND ("Information Technology") AND ("Auditory Perception"); Open Grey -

("Information Technology") AND ("Auditory Perception") AND ("Program") AND ("Acoustic Stimulation") AND ("Auditory Perceptual Disorders") AND ("Acoustic Stimulation") AND ("Auditory Perception") AND ("Telerehabilitation") AND ("Auditory Perception Disorders"); Google Scholar - ("Acoustic Stimulation") AND ("Auditory Perception Disorders") AND ("Auditory Perception") AND ("Telerehabilitation") AND ("Acoustic Stimulation") AND ("Auditory Perception") AND ("Program") AND ("Information Technology") AND ("Auditory Perceptual Disorders"). All databases were searched in English. The filter was selected for Portuguese, English, and Spanish, with publication dates between 2019 and 2025. Chart 1 presents the search strategies used in the databases.

Selection criteria

Certain eligibility criteria were established for article selection. Included studies focused on individuals diagnosed with CAPD. They addressed auditory rehabilitation through technologies, such as auditory training programs, software, or other technological tools. Only clinical and intervention studies published between 2019 and 2025 were considered. Articles needed to be available in English, Portuguese, or Spanish. Studies also had to present empirical data and analyses on the effectiveness of technologies in auditory rehabilitation.

Studies that did not present empirical data regarding the effectiveness of technologies applied to auditory training, as well as secondary studies such as non-systematic reviews and opinion articles, were excluded from the review. Thus, we sought to ensure a focus on primary research that directly addressed technology-mediated auditory rehabilitation in individuals with CAPD. Studies that did not use technological resources as a CAPD rehabilitation method with proven efficacy, as well as those that did not perform electrophysiological and behavioral assessments for the diagnosis of the disorder, were also excluded.

To select the studies, articles were first identified in PubMed/MEDLINE, LILACS/BVS, SciELO, Scopus, Cochrane Library, Open Grey, and Google Scholar. The inclusion criteria were then applied by reviewing titles and abstracts. Duplicate studies were removed. Exclusion criteria were examined after reading the full texts. Two researchers conducted the selection process independently. Inclusion criteria focused on studies that addressed technology use in auditory rehabilitation, software, and computerized programs for auditory training. Evaluation of the effectiveness of these programs and interventions was considered, using both subjective and objective measures. Electrophysiological analyses after auditory training, electrophysiological examinations, auditory behavioral assessments, and the administration of questionnaires and subjective assessment instruments were all included.

In this study, the search strategy was developed by a group of authors, whose consolidated expertise in the subject allowed for the appropriate selection and use of controlled and uncontrolled descriptors, as well as the careful definition of Boolean combinations. This approach ensured adequate sensitivity and specificity in the retrieval of relevant studies.

Data analysis

Eligible articles were organized and analyzed descriptively, considering the authors, study type, technology used, number and duration of auditory training sessions, and intervention effectiveness. Methodological strategies, participant profiles, and assessment instruments were also observed. Based on this information, we sought to identify whether auditory skills improved after using the technology. Furthermore, two authors participated in the selection of study analyses, according to the established inclusion and exclusion criteria. The selection was carried out independently by two reviewers. In cases of disagreement between the reviewers, another reviewer was appointed to make a consensus decision, without the use of software.

RESULTS

The search process and the selection of articles for this review are presented in a flowchart (Figure 1), demonstrating the extracted data and the results of all the cross-referencing

Chart 1. Search strategies used in databases

DATABASE	SEARCH STRATEGY CARRIED OUT IN MAY 2024
SciELO	("Acoustic Stimulation") AND ("Program") AND ("Auditory Perception") AND ("Information Technology") AND ("Auditory Perceptual Disorders")
PubMed/MEDLINE	("Information Technology") AND ("Auditory Perception") AND ("Acoustic Stimulation") AND ("Program") AND ("Auditory Perceptual Disorders")
Scopus	("Auditory Perception") AND ("Acoustic Stimulation") AND ("Telerehabilitation" AND ("Auditory Perception Disorders") AND ("Program") AND ("Auditory Perception") AND ("Information Technology") AND ("Acoustic Stimulation") AND ("Auditory Perceptual Disorders")
LILACS/VHL	("Auditory Perception") AND ("Acoustic Stimulation") AND ("Information Technology") AND ("Program") AND ("Auditory Perceptual Disorders") AND ("Auditory Perception") AND ("Acoustic Stimulation") AND ("Telerehabilitation") AND ("Auditory Perception Disorders")
Cochrane Library	("Auditory Perceptual Disorders") AND ("Acoustic Stimulation") AND ("Program") AND ("Information Technology") AND ("Auditory Perception")
Open Gray	("Information Technology") AND ("Auditory Perception") AND ("Program") AND ("Acoustic Stimulation") AND ("Auditory Perceptual Disorders") AND ("Acoustic Stimulation") AND ("Auditory Perception") AND ("Telerehabilitation") AND ("Auditory Perception Disorders")
Google Scholar	("Acoustic Stimulation") AND ("Auditory Perception Disorders") AND ("Auditory Perception") AND ("Telerehabilitation") AND ("Acoustic Stimulation") AND ("Auditory Perception") AND ("Program") AND ("Information Technology") AND ("Auditory Perceptual Disorders")

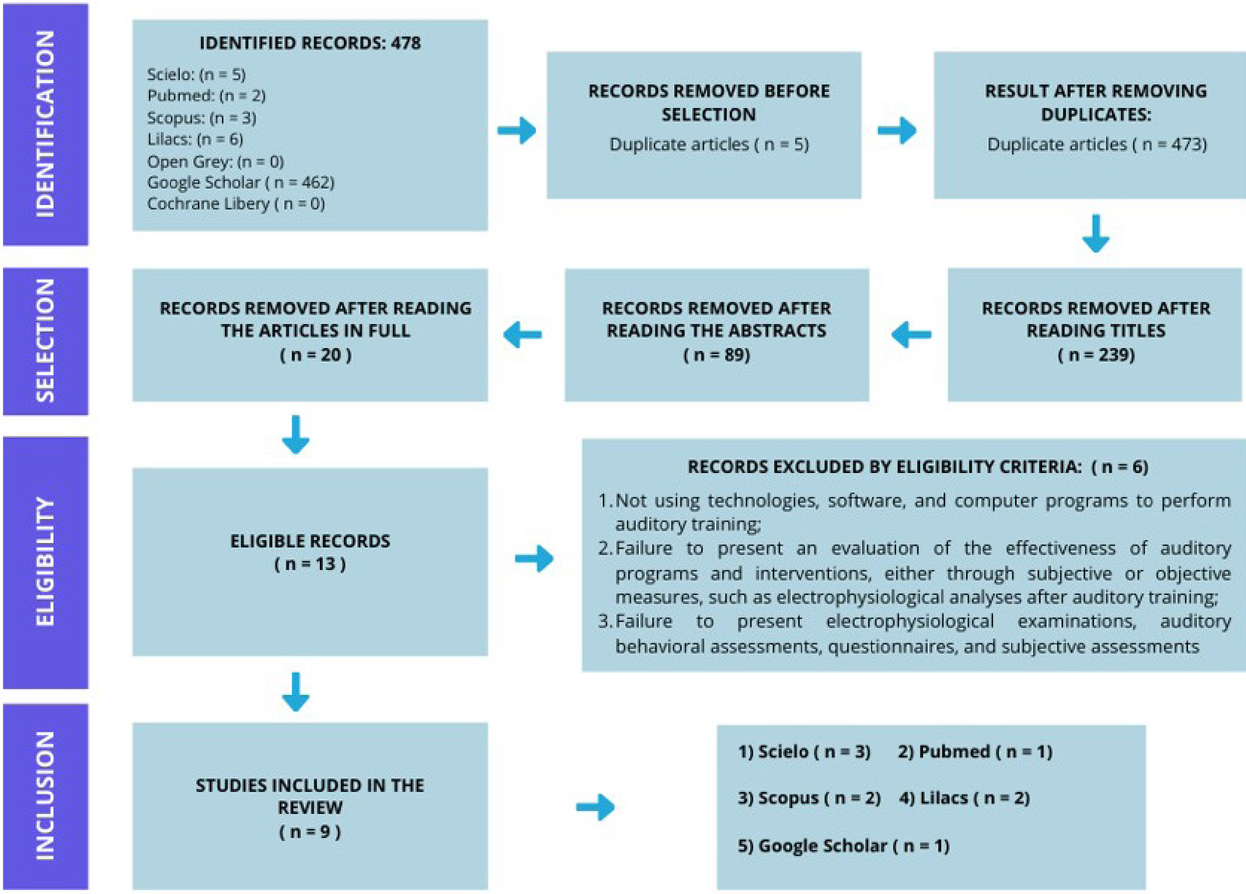

Figure 1. Flowchart showing the different phases of the review based on the guidelines of *Preferred Reporting Items for Systematic Reviews and Meta-Analyses-Extension for Scoping Reviews, 2020,* for new systematic reviews, which included searches of databases, registries, and other sources

of health descriptors in the databases, thus presenting the model of the strategy used for the proposed review and bringing the quantitative findings in the literature to the present area of study.

The initial search retrieved a total of 478 articles, covering all intersections of the descriptors in the Portuguese, English, and Spanish databases. The studies were filtered according to the steps defined in the flowchart, which were organized into four main phases: identification, selection, eligibility, and inclusion.

In the identification phase, records were collected from the following databases: SciELO (n = 5), PubMed (n = 2), Scopus (n = 3), LILACS (n = 6), Open Grey (n = 0), Google Scholar (n = 462), and Cochrane Library (n = 0). After removing 5 duplicate articles, 473 records remained for the subsequent stage. During the selection phase, 239 records were excluded after analyzing the titles, and subsequently, 89 records were eliminated after reading the abstracts. In the full-text reading stage, 20 records were removed, resulting in 13 records eligible for the eligibility phase, in which only 8 studies remained after exclusion based on the criteria.

In the final stage, the inclusion stage, 9 studies were selected for the review, distributed as follows: SciELO (n = 3), PubMed (n = 1), Scopus (n = 2), Lilacs (n = 2), and Google Scholar (n = 1). The flowchart details the systematic selection process, ensuring that only articles that met the specific eligibility criteria were included in the review.

The selected literature revealed that all 9 included articles employed technologies, software, or computerized programs for auditory training. However, only 6 articles (66.7%) performed behavioral assessments of central auditory processing, and 3 studies (33.3%) used electrophysiological tests, such as long-latency auditory evoked potentials (P300). Of the included studies, only 2 (22.2%) used questionnaires for subjective analysis, including instruments such as the Auditory Self-Assessment Questionnaire, the Hearing-Related Quality of Life Scale, the Software User Feedback Questionnaire, the Content Validation Questionnaire, the Parent/Teacher Perception Questionnaire, and the Participant Satisfaction Scale. Furthermore, only 7 studies (77.8%) demonstrated the effectiveness of auditory training. Finally, a summary chart was created to present the studies, identifying the author and year; title; type of study; technology used for auditory training; number of auditory training sessions; methodological design and outcome (Chart 2).

DISCUSSION

The analysis of the selected studies revealed important discussions about the use of technology in the rehabilitation

Chart 2. Data extracted from selected articles

Author and year of publication	Title	Type of study	Technology used	Auditory training sessions	Stimulated skills	Methodological design	Outcome
Brasil and Schochat[11], 2018	Effectiveness of auditory training using the Programa de Escuta no Ruído (PER) software in schoolchildren with auditory processing disorder and low academic performance	Intervention research	Programa de Escuta no Ruído (PER) - Software	12 sessions of 50 minutes each	Perception and discrimination, visual closure, figure-ground and visual memory	Eighteen children aged 8 to 10 years, of both genders (13 boys and 5 girls), participated in this study. The pre-intervention evaluation consisted of a basic audiological assessment (meatoscopy, acoustic immittance, pure tone and vocal audiometry), an auditory processing assessment (speech in noise, PSI, SSW, frequency pattern), and a school performance test, which comprehensively assesses fundamental skills for school performance in the areas of reading, writing, and arithmetic.	There was no statistically significant difference between the pre-intervention assessment and the reassessment of auditory processing after placebo training, but there was a statistically significant difference between the pre- and post-auditory training conditions.
Calarga et al.[12], 2018	*Translation and cross-cultural adaptation of a listening in noise auditory training software to Brazilian Portuguese*	Pilot study	*Software*Canadian Logiciel d'Écoute dans le Bruit – LEB	14 to 18 sessions of 45 minutes each	Sensory perception of the auditory signal also stimulates cognitive and linguistic skills, such as memory, attention, phonological awareness, lexical access, auditory comprehension and interpretation	Forty-two schoolchildren aged 9 to 10 years participated in this study. All subjects underwent a hearing screening with a pediatric audiometer and were reassessed with the compressed speech test – disyllabic words – 70% compression, and answered a quantitative assessment questionnaire on the LEB.	The questionnaire revealed that the LEB was well-received and stimulating, providing new learning opportunities. The GT showed significant improvements compared to the GC.
Boaz and Biaggio[13], 2020	Performance in computerized auditory training	Longitudinal, comparative, clinical and experimental study	*Software*- Active Listening	12 sessions of 30 minutes each	Figure-ground, temporal resolution and patterning, binaural integration and separation, and auditory discrimination	The sample consisted of seven children, aged between 7 years and 8 years and 11 months, of both genders. The initial assessment for sample composition consisted of the following procedures: general history taking, visual inspection of the external auditory canal, pure tone audiometry, speech audiometry, acoustic immittance measurements, and behavioral assessment of the CAP.	It was not possible to verify a significant difference between the pre- and post-training periods using the software's own evaluation stage, showing the need for further research studies to verify the use of this evaluation tool in a clinical environment.

Subtitle: SSW = Alternating Disyllabic Word Listening; PSI = Synthetic Sentence Test; GT = Trained Group; GC = Control Group; CAP = Central Auditory Processing; CD = Compact Disk

Chart 2. Continued...

Author and year of publication	Title	Type of study	Technology used	Auditory training sessions	Stimulated skills	Methodological design	Outcome
Luís et al.[14], 2023	*Auditory Processing Intervention Program for school-aged children – development and content validation*	Cross-sectional, exploratory and descriptive study, with a quantitative approach	Auditory Processing Intervention Program - PIPA	Each game/ task presents approximately 10 to 15 consecutive stimuli, and if the child achieves 75% accuracy, they can advance to the next level. The number and duration of sessions were not specified.	Auditory discrimination, auditory attention, auditory memory, closure, figure-ground; binaural separation, binaural integration, and binaural fusion	The first stage consisted of developing the program and its instruction manual, which included objectives, activities, procedures, materials, reinforcement, instructions, and verbal stimuli for the auditory skills of auditory discrimination, auditory attention, auditory memory, closure, figure-ground, binaural separation, binaural integration, and binaural fusion. The second stage consisted of content validation by two expert panels who analyzed the program using a questionnaire. Content validity was calculated using the content validity index.	The study allowed the development and validation of an intervention program in auditory processing, with verbal stimuli, selected according to strict linguistic criteria, but without the presence of acceptability and effectiveness.
Jutras[15], 2018	*Listening in noise training in children with auditory processing disorder: exploring group and individual data*	Exploratory study	Hearing training program in noise-Logiciel d' ecoute dans le bruit	13 sessions of 30 minutes	Auditory attention, auditory discrimination, auditory memory, auditory closure and temporal resolution	Ten children with auditory processing disorder underwent an auditory training program in noise, and six children with auditory processing disorder comprised a control group. Before and after training, participants were tested on sentence identification in noise and auditory evoked late-latency responses.	Hearing in noise may improve with training for children with auditory processing disorder. However, this training program may be beneficial for some children with auditory processing disorder, but not all. More data are needed to verify individual-level trends.

Subtitle: SSW = Alternating Disyllabic Word Listening; PSI = Synthetic Sentence Test; GT = Trained Group; GC = Control Group; CAP = Central Auditory Processing; CD = Compact Disk

Chart 2. Continued...

Author and year of publication	Title	Type of study	Technology used	Auditory training sessions	Stimulated skills	Methodological design	Outcome
Moreira et al.[16], 2021	Acoustically uncontrolled cognitive and auditory training for elderly population: a case study	Case study	*Softwaree*Arena®	Six 50-minute sessions	Attention, memory, figure-ground for verbal sounds, temporal ordering and resolution, auditory closure, executive functions and motor praxis	The study was carried out in three stages: (1) selection of materials, including existing materials and others created by the authors; (2) analysis by expert judges, for consensus regarding the skills evaluated and type of training; (3) application of the protocol in a clinical case, with a battery of tests for pre- and post-intervention evaluation, consisting of cognitive and auditory evaluation (behavioral and electrophysiological).	The subject of the clinical case obtained improvements after the intervention and the effectiveness was verified through behavioral tests of central auditory processing, cognitive screening and long-latency auditory evoked potential.
Skarzynski et al. [17], 2023	The Stimulation of Polymodal Sensory Perception by Skarżyński (SPPS-S): comparison *of*stationary and remote therapy results	Intervention research	Skarżyżski's Polymodal Sensory Perception Stimulation - Telerehabilitation program	Sessions lasting 5 to 15 days for 2 or 3 hours.	Temporal discrimination and resolution, binaural integration and separation	The data used to evaluate the effectiveness of SPPS-S-based therapy included the results of 100 patients who received remote SPPS-S therapy compared with the results of 100 patients who underwent therapy in a specialized center. The therapy typically consists of three levels: passive listening to specially modified sounds, relaxation, multimedia and psychoeducational games, and microphone work.	The results confirm the high effectiveness of Skarÿyÿski's Polymodal Sensory Perception Stimulation, both in stationary form and implemented remotely.
Vendruscolo et al. [18], 2023	**Cognitive Auditory Training: Comparative Impact of Telerehabilitation and In-person Training**	Comparative study	Online Cognitive Auditory Training Program	10 web sessions	Auditory closure, selective attention, binaural integration and separation	The sample consisted of 23 children aged 7 to 9 years, of both genders, divided into two groups: Group I - 13 children undergoing telerehabilitation and Group II - 10 children undergoing auditory training in a soundproof booth. The instruments used were: Pediatric Speech Intelligibility Test (PSI) in ipsilateral competitive messages (ICM condition); Dichotic Digit Test (DD) in binaural integration and separation skills in auditory separation and integration skills.	The data from this study show that the intervention through the Online Cognitive Auditory Training Program proposed and applied to school-age children contributes to the development and improvement of figure-ground auditory skills through selective attention, figure-ground skills for verbal sounds in the process of sustained attention and selective attention, and binaural integration as it explores cortical reorganization and plasticity.

Subtitle: SSW = Alternating Disyllabic Word Listening; PSI = Synthetic Sentence Test; GT = Trained Group; GC = Control Group; CAP = Central Auditory Processing; CD = Compact Disk

Chart 2. Continued...

Author and year of publication	Title	Type of study	Technology used	Auditory training sessions	Stimulated skills	Methodological design	Outcome
Sakai et al.[19], 2020	**Auditory abilities stimulation in preschoolers**	Prospective, analytical and interventional	Informal therapy using CDs with recorded sounds.	8 sessions	Sound localization and memory	To evaluate the effects of the informal auditory training program intervention, the following procedures were performed pre- and post-intervention: meatoscopy, tympanometry and simplified assessment of central auditory processing.	Comparison of preschoolers' performance in the test and retest revealed significant improvements in all auditory skills assessed. Preschoolers performed better in sound localization and worse in sequential memory of nonverbal sounds in both the test and retest.

Subtitle: SSW = Alternating Disyllabic Word Listening; PSI = Synthetic Sentence Test; GT = Trained Group; GC = Control Group; CAP = Central Auditory Processing; CD = Compact Disk

of central auditory processing disorder (CAPD). The primary objective was to present scientific evidence on the effectiveness of various technological tools used in auditory training and to identify the types of technologies employed based on their effectiveness.

Among the eight articles reviewed, it was observed that most participants with CAPD showed significant benefits from the use of specific technologies for auditory training. This finding reinforces the importance of developing methodologies based on scientific evidence that are effective for the target audience. One of the studies analyzed showed that technologies such as Active Listening software may not be universally effective, as they did not demonstrate significant improvements in the auditory skills of children undergoing training[13]. However, the authors attributed the low effectiveness to the short time interval between the end of the activities and the reassessment conducted by the computer program, which occurred at the end of the tenth session[13].

The reviewed studies revealed a variety of methodologies and results in auditory training aimed at different populations. The effectiveness of the programs varied according to the methodological design, the technology used, and the characteristics of the participants. Therefore, the analyzed studies demonstrated that auditory training programs conducted with an average frequency of two weekly sessions were those that presented the most consistent and statistically significant results in the rehabilitation of auditory skills in individuals with CAPD[11,12,15,18,20]. This frequency was observed to be effective in both in-person training and telerehabilitation formats. Although other application schemes, such as daily or weekly sessions, have also been used, the two-weekly session program stood out for favoring the neural plasticity and cortical reorganization necessary for improving auditory performance, especially in skills such as figure-ground, binaural integration, and auditory closure[11,18].

One of the studies analyzed demonstrated that simple and informal interventions can be effective in improving auditory skills in preschoolers, suggesting that exposure to auditory stimuli contributes to strengthening these capacities[19]. In contrast, another study showed that the use of specialized software, such as the Programa de Escuta no Ruído (PER), presents positive results in schoolchildren with specific hearing difficulties, highlighting the importance of structured and targeted interventions[11]. Thus, while some studies point to the effectiveness of simple methods in informal contexts[19], others emphasize the relevance of more advanced technological approaches to meet more complex auditory demands[11].

Cultural adaptation of auditory training tools is an essential process to ensure the acceptance and effectiveness of programs in local contexts. This procedure is generally preferable to developing a new instrument in another language, as it is more agile and less costly. Furthermore, adapted instruments tend to offer greater safety to users, as they are based on previous successful experiences, unlike newly developed instruments[12].

Integrating simple, accessible interventions into school and home settings may be appropriate for stimulating the auditory skills of preschoolers who have not been diagnosed with CAPD, while more structured programs may be more effective for children with specific language and auditory processing disorders. Cultural adaptation and personalized interventions are essential to meet individual needs and ensure the effectiveness of the tools.

The discussion of the studies reinforces the need for diverse and adaptable approaches in auditory training. Personalizing interventions should be a priority to meet the specific needs of individuals. The results indicated that a well-structured and validated program can be effective in intervening in auditory processing in children, highlighting the importance of content validation by experts[14]. Furthermore, it has been suggested that combined cognitive and auditory interventions may be beneficial for older adults, improving both cognitive and auditory abilities[16]. Telerehabilitation has been shown to be as effective as in-person therapy, offering a viable and accessible alternative, providing flexibility in the treatment of auditory skills[17,18]. However, the variability in response to interventions highlights the need for continued personalization and further studies to understand the factors that influence effectiveness. The integration of cognitive components may offer additional benefits, especially for older populations.

When analyzing the effectiveness and approaches of auditory training software, a variety of applied methodologies were observed, each with different focuses and objectives. Most of the studies (55%) reviewed adopted a bottom-up approach, which prioritizes the improvement of basic auditory skills, such as sound discrimination, before advancing to more complex cognitive processes. Examples of this approach include the use of an informal auditory training program to stimulate auditory sound localization skills and sequential memory of verbal and nonverbal sounds[19], as well as a focus on improving sound discrimination ability in noisy environments through the Programa de Escuta no Ruído (PER) software[11]. Both studies[11,19] exemplify how strengthening fundamental auditory skills is considered the crucial first step, indirectly influencing neurocognitive functions such as attention and auditory memory.

However, some studies have explored a more comprehensive approach that incorporates neurocognitive elements into auditory training, stimulating cognitive and linguistic skills, such as memory and auditory comprehension[12]. This approach aims not only to improve auditory perception but also to integrate these skills with higher cognitive processes, promoting neuronal reorganization through multisensory stimulation. Similarly, an online platform was used to integrate bottom-up and top-down approaches, maximizing the benefits of auditory rehabilitation[18].

The number of sessions required to obtain significant results in auditory training varied considerably among studies. One study reported the use of 12 sessions lasting 50 minutes each[11], while another indicated between 14 and 18 sessions of 45 minutes[12], and another recommended 12 sessions of 30 minutes[13]. This variation reflects the diversity in approaches and objectives of different auditory training programs. However, the ideal duration of auditory training is not yet well established in the literature, varying depending on factors such as the nature of the hearing disorder, the specific training objectives, the patient's age, and the methodologies employed. Therefore, acoustically controlled auditory training programs, considered the gold standard for the rehabilitation of auditory skills in CAPD, should, regardless of the computer interface used, be conducted in sessions lasting approximately 30 minutes, with an average of 8 to 13 sessions[21].

Compared with therapy without the use of software, some studies have indicated that therapy with software can be equally effective, but the number of sessions required may vary[16]. One study suggested that telerehabilitation, although effective, requires daily sessions of two to three hours[17], while another demonstrated that telerehabilitation and auditory training in an acoustically controlled booth can be equally effective, although the number of sessions required may be diferente[18].

Acoustic control during auditory training is crucial to ensuring effective results. Studies have emphasized the importance of acoustic control, adjusting the signal-to-noise ratio according to participant performance to ensure a more challenging and effective training environment[11,15]. However, some studies have not employed acoustic control, which can limit training accuracy and results[13,19]. Therefore, the choice of approach—bottom-up or neurocognitive—as well as the number of sessions and acoustic control are determining factors for the effectiveness of auditory training. The use of software offers a differentiated and potentially more stimulating therapeutic approach, although its effectiveness compared to traditional therapy still requires further direct comparative studies.

The evaluation of data related to auditory training software highlighted fundamental considerations regarding registration, usability testing, and accessibility. These factors are crucial for analyzing the effectiveness and applicability of these resources in auditory rehabilitation. Regarding software registration, significant variation was observed between studies. While some indicated that the evaluated software is registered[12,16], others did not mention this information[11,13-15,17]. The lack of registration data in most studies likely indicates a potential gap in the regulation of these software programs, which may compromise their reliability and acceptance in clinical settings.

Regarding usability testing, studies have presented diverse approaches. Some studies focused directly on evaluating usability in the real-world context of application[11,14], highlighting the importance of testing the effectiveness of software in practical situations. Other studies adopted pilot or exploratory approaches[12,15], while interventions conducted in controlled environments have also been described in the literature[13,17]. Furthermore, there are contributions that highlight the relevance of clinical studies in evaluating the effectiveness of software in improving speech understanding and users' quality of life[16].

Software accessibility also varied among the studies analyzed. One study described free software with language accessible to children[12], while others indicated that the software evaluated is commercially available and aimed at professionals or specialized clinics[13,16]. This restriction may limit access to these resources, restricting their benefits to a limited group of users.

Limitations of this review and other studies include the fact that some studies found no statistically significant differences in auditory skills after training, suggesting the need for further research to validate the effectiveness of certain technologies, especially in clinical settings. The heterogeneity of methods, technologies employed, and evaluation criteria also highlights the need for standardization and the development of more robust protocols.

While technologies have demonstrated significant potential in the rehabilitation of individuals with CAPD, it is essential that future studies further explore the mechanisms underlying the hearing improvements provided by these tools. Continuous technological evolution offers a valuable opportunity to refine therapeutic approaches, enhancing patient benefits and contributing to more efficient, evidence-based clinical practice.

The analysis of the studies highlighted the heterogeneity of the population diagnosed with central auditory processing disorder (CAPD). The samples mainly included school-age children, ranging from 7 to 10 years old[11-14,18], although there are records of interventions also in adults and the elderly[16], which demonstrates that CAPD can manifest in different age groups. Regarding gender, the participation of both genders was observed, with a predominance of males in some samples[11].

The conditions associated with CAPD also varied across studies. Many participants had low academic performance[11,14,18], while other studies included cognitive and motor aspects as intervention targets[16]. Response to the intervention also revealed considerable variability. Some studies reported significant improvements in auditory skills after training[11,12,17], while others highlighted the need for further investigation due to the lack of statistically significant differences between pre- and post-intervention periods[14,15]. This diversity of responses indicates that not all individuals with CAPD benefit equally from the same auditory training programs.

CONCLUSION

Based on the literature review, it appears that technologies are emerging as effective tools for enhancing the auditory rehabilitation process, promoting neural plasticity, and improving central auditory skills. The auditory training programs, software, and applications analyzed show positive results in most studies, demonstrating their ability to adapt to users' specific needs and promote improvements in auditory performance.

Furthermore, the reviewed studies show that the use of technology facilitates patient adherence to auditory training, as these tools make the process more dynamic, accessible, and motivating. Automatic difficulty adjustment in the programs analyzed, based on user performance, is a particularly important aspect for ensuring training effectiveness.

Although some studies do not emphasize statistically significant differences in post-intervention performance, it is possible to affirm that technologies constitute promising tools in the treatment of central auditory skills with positive trends and relevant clinical improvements in these skills, which suggests that technologies can favor auditory training, especially when associated with well-structured and personalized protocols.

However, it's important to note that not all technological resources used in auditory training programs automatically adjust difficulty. This is highly relevant, since continually adapting the challenge level to individual capabilities is considered a determining factor in training effectiveness. Programs that incorporate automatic adjustments tend to promote greater individual engagement and favor the consolidation of trained auditory skills, respecting the principles of neural plasticity and progressive learning.

Therefore, although technologies represent an important advance, the effectiveness of auditory training mediated by these resources depends on the quality of the program, the presence of adaptive mechanisms, and its suitability to the specific needs of each individual.

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