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Auditory processing abilities in pitch and duration pattern tests for elderly: a systematic review

Habilidade do Processamento auditivo no teste de padrões de frequência e de duração em idosos: uma revisão sistemática

Habilidades de procesamiento auditivo en pruebas de patrones de tono y duración para ancianos: una revisión sistemática

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Abstract

Purpose: to analyze the performance of elderly people with hearing loss compared to normal-hearing elderly people in the Pitch Pattern Sequence Test (PPS) and Duration Pattern Sequence Test (DPS). **Research strategy:** Electronic search strategies were individually developed for each of the following databases**:** LILACS, LIVIVO, Pubmed, Scopus, SpeechBITE and Web of Science. Grey literature was searched by using Google Scholar, OpenGrey and Proquest Dissertations and Theses. **Selection criteria:** Observational studies that evaluated elderly (over 60 years old) with age related hearing loss or presbycusis, ranging from mild to moderately severe, with different scores, compared to normal hearing for pitch

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(PPS) or duration pattern sequence (DPS) tests were included. The methodology of selected studies was evaluated using Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI) critical appraisal tools for cross sectional studies. No restrictions regarding language, period of publication or gender were applied. **Results:** Title and summary of 1042 articles were analyzed after duplicates were removed. From this analysis, the full texts of 15 articles were analyzed. Five studies were included in this systematic review, three studies used the Musiek DPS version, two used the Auditec DPS and PPS version. Risk of bias was low (three studies) and moderate (two studies), according to this protocol. **Conclusion:** This systematic review showed no score differences between groups with presbycusis compared with normal hearing for DPS and PPS test. More primary studies utilizing the same protocol for PPS and DPS are needed.

Keywords: Systematic review; Aging; Auditory perception; Hearing tests; Audiology.

Resumo

Objetivo: analisar o desempenho de idosos com perda auditiva em comparação a idosos normo-ouvintes no teste de padrões de frequência (TPF) e duração (TPD). **Estratégia de pesquisa:** As estratégias de busca eletrônica foram desenvolvidas individualmente para os seguintes bancos de dados: LILACS, LIVIVO, Pubmed, Scopus, SpeechBITE e Web of Science. A literatura cinzenta foi pesquisada usando o Google Scholar, OpenGrey e Proquest Dissertações e Teses. **Critérios de seleção:** Foram incluídos estudos observacionais que avaliaram idosos (acima de 60 anos) com perda auditiva relacionada à idade ou presbiacusia, variando de leve a moderadamente grave, com diferentes escores em comparação a idosos com audição normal no TPF e TPD. A metodologia dos estudos selecionados foi avaliada por meio de ferramentas de avaliação crítica Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI) para estudos transversais. Não foram aplicadas restrições quanto ao idioma, período de publicação ou sexo. **Resultados:** O título e o resumo de 1042 artigos foram analisados após a remoção das duplicatas. A partir desta análise, foram analisados os textos completos de 15 artigos. Cinco estudos foram incluídos nesta revisão sistemática, três utilizaram o TPD na versão de Musiek e dois a da Auditec do TPF e TPD. O risco de viés foi baixo (três estudos) e moderado (dois estudos), de acordo com este protocolo. **Conclusão:** Esta revisão sistemática não mostrou diferenças de escores entre os grupos com presbiacusia em comparação com a audição normal no TPF e TPD. São necessários mais estudos primários utilizando o mesmo protocolo para TPF e TPD.

Palavras-chave: Revisão sistemática; Envelhecimento; Percepção auditiva; Testes auditivos; Audiologia.

Resumen

Objetivo: analizar el desempeño de ancianos con hipoacusia en comparación con ancianos con audición normal en la prueba de patrones de frecuencia (PPF) y duración (PPD). **Estrategia de búsqueda**: Se desarrollaron estrategias de búsqueda electrónica individualmente para las siguientes bases de datos: LILACS, LIVIVO, Pubmed, Scopus, SpeechBITE y Web of Science. Se realizaron búsquedas en literatura gris utilizando Google Scholar, OpenGrey y Proquest Dissertations and Theses. **Criterios de selección:** Se incluyeron estudios observacionales que evaluaron a ancianos (mayores de 60 años) con pérdida auditiva relacionada con la edad o presbiacusia, que van de leve a moderadamente severa, con puntajes diferentes en comparación con ancianos con audición normal en PPF y PPD. La metodología de los estudios seleccionados se evaluó utilizando herramientas de evaluación crítica Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI) para estudios transversales. No se aplicaron restricciones en cuanto a idioma, período de publicación o género. **Resultados:** Se analizaron el título y resumen de 1042 artículos después de eliminar los duplicados. A partir de este análisis, se analizaron los textos completos de 15 artículos. Se incluyeron cinco estudios en esta revisión sistemática, tres utilizaron el PPD en la versión Musiek y dos en la versión Auditec del PPF y PPD. El riesgo de sesgo fue bajo (tres estudios) y moderado (dos estudios), según este protocolo. **Conclusión:** Esta revisión sistemática no mostró diferencias en las puntuaciones entre los grupos con presbiacusia en comparación con la

audición normal en PPF y PPD. Se necesitan más estudios primarios que utilicen el mismo protocolo para PPF y PPD.

Palabras clave: Revisión sistemática; Envejecimiento; Percepción auditiva; Pruebas de audición; Audiología.

Introduction

The American Academy of Audiology (AAA)[1] defines Central Auditory Processing Disorder (CAPD) as a perceptual difficulty in processing auditory information in the central nervous system.[1] Its symptoms involve changes in speech perception and impaired neural function, which may include afferent and efferent pathways of the central auditory nervous system (CANS).

The British Society of Audiology (BSA) has published a guide that highlights the importance of evidence-based discussion and practice and the promotion of collaboration between researchers from different areas and countries for CAPD evaluation and diagnosis.[2-3] Tests selected for CAPD assessment should include a variety of auditory processes. The battery must include tests that require dichotic and temporal processing, auditory closure, and auditory foreground-background differentiation. These tests must assess different regions of CANS[4] and include verbal and nonverbal tasks. The most commonly used are pitch and duration pattern sequence tests and tests including dichotic words or sentences and degraded speech or speech in noise.[5] There are controversies about the existence of standardized tests to validate the diagnosis of CAPD.[1,3] The BSA suggests a reduction in the number of tests so as to increase quality and reliability. In the meantime, the organization also proposes the validation of clinical protocols for CAPD.[2]

The elderly corresponds to a significant portion of the people who have been referred for assessment of central auditory processing. The prevalence of CAPD in the elderly ranges from 22.6%[6] to 50%.[7] The last BSA review included aging as a cause of acquired CAPD,[2] which results from the deterioration of auditory processing skills.[8]

Many of the tests used to assess central auditory processing in the elderly can be influenced by peripheral hearing loss, which is a strong confounding factor. It is important that a central auditory processing test is not affected by the presence of high-frequency peripheral sensorineural hearing loss, given the high prevalence of this hearing loss. A study with this population found that, regardless of auditory condition, the elderly had lower mean scores and standard deviations than young people in most central auditory processing tests.[9]

The main hearing complaint reported by the elderly is the difficulty of understanding speech in noise, and hearing loss cannot consistently justify it.[10] Temporal processing is the physiological mechanism of hearing most affected by aging.[11]

The BSA states that CAPDs may include auditory and cognitive elements at all ages.[3,5] The general objective of CAP assessment is to access auditory processing skills and language skills, in which the use of tonal materials is appropriate. This is the case of pitch pattern sequence (PPS) tests and duration pattern sequence (DPS) tests.[4]

Temporal ordering is the recognition of two or more auditory stimuli in the order of their occurrence. The PPS and DPS have nonverbal presentation and are the most used clinical tests for temporal ordering.[12] The PPS[13] consists of three 150-ms tone bursts and two 200-ms intertone intervals. The tones in each pitch pattern are combinations of two sinusoids, 880 Hz and 1122 Hz, corresponding to a low frequency and a high frequency, respectively. The DPS[13] consists of three 1000-Hz tone bursts and two 300-ms intertone intervals. The tones in each duration pattern last for 250 msec or 500 msec, corresponding to a short duration and a long duration, respectively. Therefore, there are six possible combinations of the three-tone sequence in both tests. Authors recommend that these tests be part of any battery of central tests, as they are easy and quick to apply[13,14] and are essential tests in CAP assessment.[5] An increasing number of studies have used nonverbal tests to assess central auditory dysfunction so as to minimize language bias.[3,15,16] Noteworthy, PPS is included in the battery of standard tests for the diagnosis of central auditory disorder.[16]

A systematic review was performed on normative studies based on central auditory processing that included PPS or DPS tests, available in several

languages.[13,14,17-27] Other studies have analyzed the hearing loss bias.[9,11,28-34] However, in studies that interpret how age influences temporal processing, it is difficult to separate the hearing loss bias. Thus, it is necessary to study the scientific evidence of PPS and DPS tests in different populations, mainly in the elderly, commonly affected by presbycusis. Likewise, it is important to study the influence of cochlear lesions on temporal information[34] since CAP can be a predictor of successful adaptation of binaural hearing aids.[1] Thus, this review is necessary to clarify the proper use of these temporal tests in CAPD assessment in elderly people with sensorineural hearing loss.

Objective

This study aimed to compare the performance of elderly people with and without hearing loss in pitch and duration pattern tests. Thus, the question of the systematic review was: "Is there a difference in the performance of elderly people with and without hearing loss in pitch and duration pattern tests?".

Research strategy

The PICOS (Population, Intervention, Comparison, Outcome, and Study design) strategy was used to formulate the focus of this systematic review. The strategy consisted of: P - population: elderly; I - intervention: mild to moderately severe hearing loss due to aging; C - comparison: normal hearing; O - outcome: difference in Pitch Pattern Sequence (PPS) and Duration Pattern Sequence (DPS) scores; and S - study design: observational studies.

Electronic search strategies were developed individually for each of the following databases: LILACS, LIVIVO, Pubmed, Scopus, SpeechBITE, and Web of Science (Appendix 1). An additional grey literature search was conducted by accessing ProQuest (dissertations and theses), OpenGrey, and Google Scholar. Moreover, experts were consulted to identify any important publications missing from the search results. A reference management software (EndNote® X8 Thompson Reuters, Philadelphia, PA) was used to collect references and exclude duplicates. An online data manager (Rayyan QCRI) was used for reading and selecting titles and abstracts. A manual search was also performed on all references cited in the selected articles. The search of the databases was carried out on May 13, 2018 and updated on July 12, 2020. No restrictions were applied as to language, publication date, or gender.

A systematic review protocol was developed based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).[35] The protocol was registered in the Prospective Register of Systematic Reviews (PROSPERO),[36] available under the number CRD42018105972.

Inclusion criteria

The review included observational studies that evaluated elderly (over 60 years) with mild to moderately severe hearing loss due to aging or presbycusis, who performed pitch and/or duration pattern tests.

Exclusion criteria were: (a) adults under 60 years of age, according to the statute of the elderly;[37] (b) history of language, learning, neurological or related disorders; (c) electrophysiological test or central auditory processing tests other than PPS and DPS; (d) absence of comparison between the groups with and without hearing loss and results not clearly described; (e) reviews, letters, personal opinions, book chapters, conference abstracts, case reports, and case series.

Selection was carried out in two phases. In phase 1, two reviewers independently reviewed the titles and abstracts of all citations from the identified electronic databases. Articles that did not meet the inclusion criteria were discarded. In phase 2, the same reviewers applied the inclusion criteria to the full text of the articles. The list of references for the selected studies was critically assessed by both examiners. Any disagreement in the first or second phase was resolved by discussion until mutual agreement between the two authors was attained. In the absence of consensus, a third author took part in the final decision.

Data analysis

The collected data consisted of: study characteristics (author, year of publication, country, type of study), population characteristics (sample size for presbycusis and for normal hearing, age of the participants), temporal test (PPS, DPS), commercial version used (Musiek or Auditec), presentation (monoaural or binaural), response method (verbal

or humming), and the score (including mean and standard deviation) for each group of participants (Table 1). An email was sent to an author about missing data and he replied that he no longer had the data. Therefore, the study had to be excluded. Two emails were sent to experts to identify any missing important publications.

The methodology of the selected studies and risk of bias for cross-sectional studies were assessed through the critical assessment tools of the Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI).[38] This assessment was carried out independently by the first and second reviewers. Disagreements were resolved with the help of a third author. Figure 2, on risk of bias, was generated by the RevMan[39] software. RevMan questions were changed to MAStARI questions to suit the type of study. Risk of bias was categorized as high when the study reached up to 49% of "yes" scores; moderate when the study reached 50% to 69% of "yes" scores; and low when the study reached more than 70% of "yes" scores.

Differences in the mean scores of the tests were used in the two groups (normal hearing and presbycusis) and in the analysis of continuous data (mean and standard deviation).

A descriptive analysis of the results was performed according to the score of the groups with and without hearing loss. Statistical analysis, risk of bias, and group characteristics were described. In order to reduce heterogeneity between studies, the results were synthesized according to the type of study, test version, type of presentation (monoaural/binaural), and type of response, as recommended by expert consensus.

Clinical heterogeneity between studies was assessed by comparing the variability between the gender and educational level of participants. In turn, methodological heterogeneity, which includes the number of items presented, test version, type of presentation (monoaural/binaural), and type of response was assessed by comparing variability in cross-sectional studies and risk of bias in individual studies.

Results

In phase 1, 1.818 citations were collected from the electronic databases, of which 809 remained after removing duplicates. In addition, 37 references were retrieved from the grey literature and 2 from the reference list of included articles, totaling 848 articles. An expert responded to the email sent to him, but did not indicate any study. A total of 348 articles were found in the update, of which 164 remained after removing duplicates.

In phase 1, the evaluation of titles and abstracts included 15 articles for full-text analysis. In phase 2, full-text reading excluded 10 studies based on the described eligibility criteria (Appendix 2). Thus, only 5 studies intended to answer the main research question were included for the final systematic review. Figure 1 shows the selection and exclusion processes.

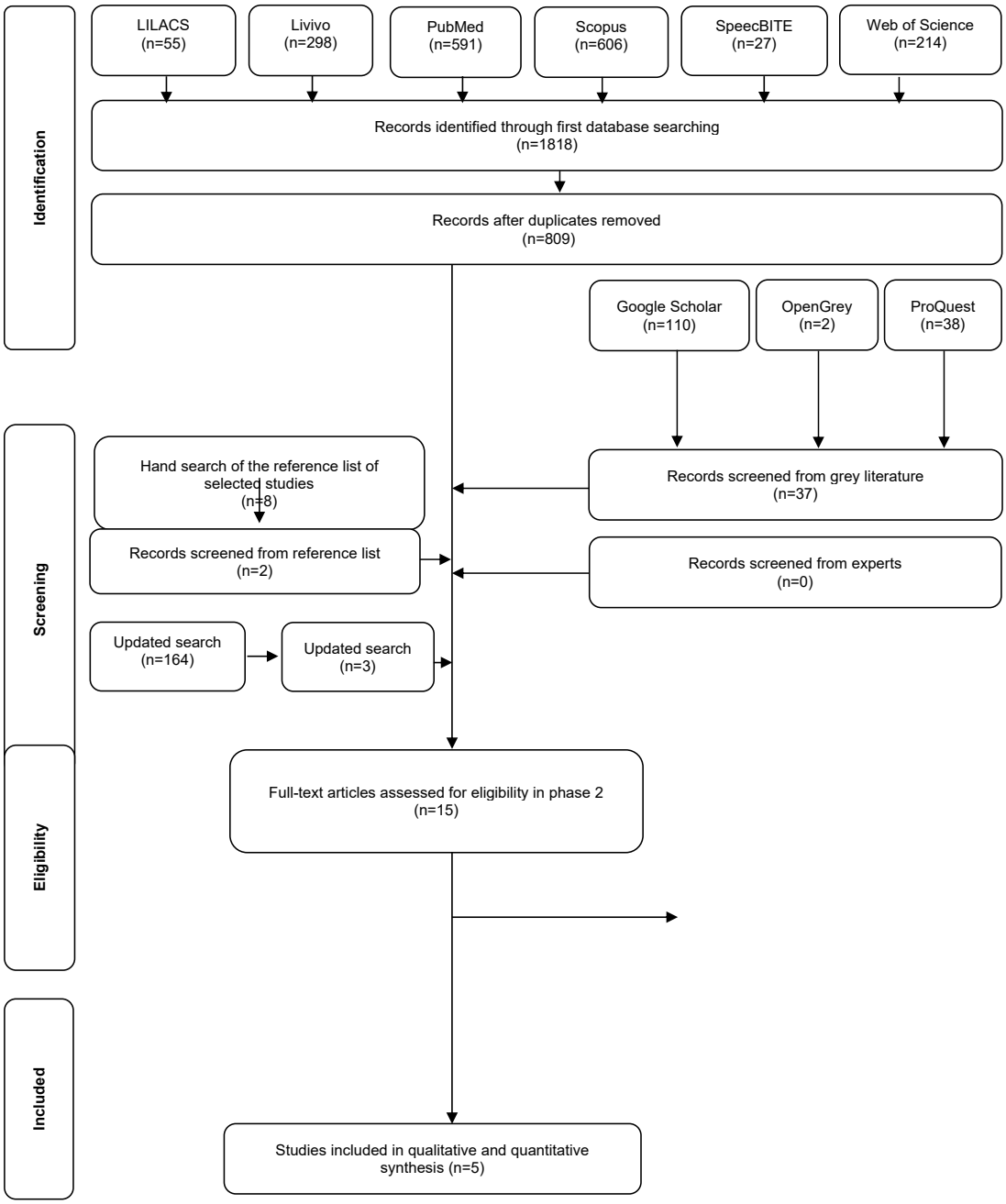


Figure 1. Flow Diagram of Literature Search and Selection Criteria (Adapted from PRISMA).

Sample size in the studies ranged from 5 to 26 healthy patients and from 8 to 22 patients with presbycusis. All patients underwent the PPS test. All included studies were cross-sectional. Table 1 shows a summary of the characteristics of the five included studies.

Three studies were classified as having a low risk of bias, one[30] with 100% "yes" answers to the eight questions of the quality assessment instrument. Thus, meeting all methodological quality criteria, the other study[11] reached 75% "yes" answers. Two studies[29,31] were classified as having a moderate risk of bias, reaching 50%

Table 1. Summary of the characteristics of the included studies (n= 5)

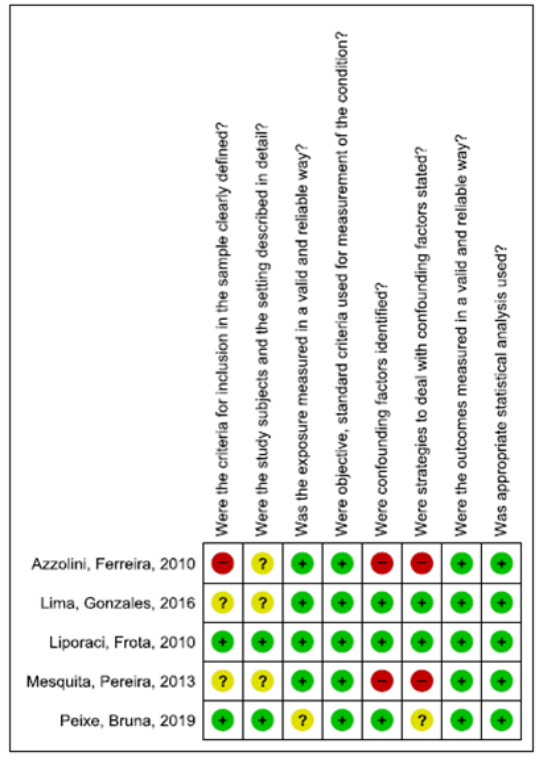
Author, Years, Country	Type of study	Sample (N)	Age range (yrs)	Test, Version	Presentation	Response type	SCORE		
							NH Mean %(SD)	PB Mean %(SD)	P value
Azzolini, Ferreira, 2010 Brasil	Cross sectional	13 NH 8 PB	60-81	PPS Auditec DPS Auditec	Binaurally Binaurally Binaurally Binaurally	Humming Verbally Humming Verbally	69.23 (33.7) 39.23 (36.3) 64.62 (35.0) 50.77 (37.5)	83.75 (19.9) 57.50 (27.1) 66.13 (32.3) 43.75 (28.7)	0.372 0.342 0.913 0.635
Lima, Gonsalez, 2016 Brasil	Cross sectional	15 NH 15 PB	60-75	DPS Musiek	Binaurally	Verbally	83.50 (25.8)	77.00 (18.2)	0.691
Liporaci, Frota, 2010 Brasil	Cross sectional	26 NH 22 PB 17 PB	60-79	DPS Musiek	Binaurally	Verbally	57.50 (25.6)	69.00 (24.9) 63.90 (25.4)	0.290
Mesquita, Pereira, 2013 Brasil	Cross sectional	5 NH 10 PB	> 60	DPS Musiek	Binaurally	ND	84.60 (13.0)	78.00 (8.4)	0.248
Peixe, Bruna 2019 Brasil	Cross sectional	12NH 11PB	>60	PPS Auditec DPS Auditec	Binaurally	ND	94.99 (6.28) 87.78 (12.50)	92.12 (8.73) 80.00 (18.32)	0.379 0.287

Legend: DPS = Duration pattern sequence; PPS = Pitch pattern sequence; Y = Young adults; E = Elderly; N= number of participants; NH = Normal hearing group; PB = Presbycusis group; ND = Not described

"yes" answers. Figure 2 and Appendix 3 show all aspects evaluated.

Azzolini and Ferreira[29] analyzed a sample of 16 women and 5 men. They measured two types of response (humming and verbal) and made 10 presentations for each type of response, totaling 20 presentations. Hearing thresholds were up to 25 dB HL for the control group, and ranged from 25 dB to 60 dB HL for the presbycusis group. Noteworthy, DPS scores were lower for men in humming condition (p = 0.008). The results of the PPS test did not show statistically significant differences between groups with and without presbycusis (p = 0.635). The authors also compared the results of the PPS test in both groups, not finding any statistically significant differences between them (p = 0.324). Risk of bias was moderate.

Lima and Gonsalez[11] evaluated 30 subjects. The authors did not describe the percentage of each gender in the sample. Hearing thresholds for the control group were up to 25 dB HL at 500, 1,000, and 2,000 Hz. For the presbycusis group, hearing thresholds were up to 60 dB HL. The presentation level was 50 dB HL for elderly people with normal hearing and 30 dB HL for elderly people with presbycusis. The authors compared the effects of educational level on the DPS test and performed a



Legend: (+): low risk of bias; (-): high risk of bias; (?): unclear

Figure 2. Risk of Bias Summary

cognitive screening battery with the Mini-Mental State Examination (MMSE)[39]. The correlation coefficients between DPS and educational level (p = 0.914) showed that this temporal test was not influenced by educational level. In addition, the correlation between DPS and age (p = 0.17) showed that age did not affect the test as well. Even with a significant difference between groups regarding age (p = 0.024) and educational level (p = 0.002), since the group with presbycusis had less schooling and was older, the elderly with hearing impairment performed similarly (p = 0.691) to the elderly with normal hearing in the DPS. Risk of bias was low.

Liporaci and Frota[30] evaluated 65 individuals, 46 women and 19 men, with a mean age of 67.3 years. They showed 45 patterns, binaurally. The study was divided into three groups: control group (G1), with normal hearing, and two study groups that differ in terms of hearing loss at high frequencies, from mild (G2) to moderate (G3). There was a statistically significant difference in mean age between groups G3 (69.4) and G1 (65.9). There were no statistically significant differences in the results of the DPS test between groups (p = 0.29). The Mini-Mental State Examination[39] was the cognitive screening battery used to minimize confounding factors. Risk of bias was low.

Mesquita and Pereira[31] evaluated 15 individuals of both genders. The number of participants of each gender was not described, nor the number of presentations. Hearing thresholds were up to 25 dB HL for the control group, and 25 dB to 70 dB HL for the presbycusis group. The correlation test between age and DPS scores was not statistically significant (p = 0.477). Differences in DPS scores between groups with and without hearing loss were not statistically significant (p = 0.248).

Peixe et al.[32] evaluated elderly people over 60 years of age, 11 with normal hearing and 12 with mild to moderate sensorineural hearing loss. All scored above 75% in the dichotic digit test. All underwent PPS and DPS, and there was no significant difference in performance in relation to the presence of hearing loss.

Regarding the research question "Is there a difference in the performance of elderly with hearing loss in comparison to normal-hearing elderly in pitch and duration pattern tests?", each selected study presents relevant information.

Three studies used the Musiek version of the tests.[11,30,31] Two studies[29,32] used the Auditec version of the DPS test. Liporaci[30] divided the study group in two, depending on the degree of hearing loss. The other studies separated the groups according to the presence (study group) or absence (control group) of hearing loss. They all had the same methodology for the type of presentation. Only one study tested PPS and found no statistical significance in the scores between groups with and without hearing loss. The five studies included did not find statistical significance in the scores of groups without hearing loss in comparison to the group with presbycusis. These were the only studies that aimed to compare DPS scores regarding the presence or not of hearing loss.

The included studies used a similar methodology, which reduced the possibility of interpretation errors. They had the same kind of response and presentation. Two studies had a different trial version. Educational level and cognition were confounding factors that were not well known; some studies did not consider them. The number of presentations ranged between 10 and 45 between studies, but not all studies had this information. Test scores were given as a percentage (Appendix 3).

Discussion

This systematic review investigated the influence of age-related hearing loss on PPS and DPS. This influence is not evident in these tests when observing the performance of elderly people with and without hearing loss.

Presbycusis refers to age-related physiological changes in the peripheral and central auditory system, which lead to hearing loss and difficulty in understanding spoken language.[7]

It is noteworthy that the studies included in this review involved elderly subjects with hearing loss and without evidence of other neurological injuries. However, there was no differential information on whether presbycusis was sensory, neural, mechanical, or metabolic since this is a complex topodiagnosis.

Some studies have demonstrated the negative impact of peripheral hearing loss on performance in central hearing tests.[2,34] In fact, some tests are affected by hearing loss, as shown by Humes et al..[9] These authors compared elderly and young adults with a battery of ten auditory processing tests, including PPS and DPS. Regardless of hearing condition, the elderly had lower scores than

young people in most tests. As a result, the group of elderly people with sensorineural hearing loss performed significantly worse than the other two groups in five tests, but this result was not evident in the PPS and DPS.[9]

All studies in this systematic review applied the test by binaural presentation, a condition that allowed its grouping.[11,29-32] At the beginning, when this test was published, it was done in a monoaural condition,[20,28,42] which can prolong the time it takes for the individual to finish the test, especially the elderly. In fact, several studies proceed in the binaural condition.[43] Other studies that performed these tests in adults in the monoaural condition compared ear scores and found no statistically significant differences.[19,20,22-24] Two other studies investigated ear differences for the monoaural condition in the elderly and found no significant differences for PPS.[14,26] One of them also tested for DPS, finding no statistical difference as well.[14]

The American Academy of Audiology states that CAPD assessment can be done in elderly people with hearing loss and good speech recognition skills through tests that are less affected by cochlear hearing loss. The institution suggests the inclusion of the PPS test[1] since its authors claim that the test is not influenced by hearing loss as long as the stimuli are audible.[13,44] For PPS, Musiek found no significant differences between groups with and without hearing loss, but the study did not include elderly people.[28]

In Brazil, the prevalence of presbycusis is 40% for women and 60% for men.[45] The BSA recognizes that central hearing disorders and associated behavioral hearing difficulties can be highly prevalent in the elderly and can be a predictor of success with binaural hearing aids.[2] Studies on the fitting of hearing aids[46,47] have shown that CAPD can impair adaptation, while auditory training indicated improvement in auditory processing skills. One study showed statistically significant differences between groups with and without auditory training ($p < 0.001$) and benefited hearing aid adaptation.[46] The American Speech-Language-Hearing Association (ASHA) states that tests that employ stimuli that are minimally affected by hearing loss should be selected whenever possible in the evaluation of individuals with hearing loss.[48] Therefore, it is important to ensure that elderly with presbycusis have access to an exam with a reliable test that is not affected by age-related hearing loss. This will assist the clinician in the diagnosis and appropriate treatment for a good adaptation of hearing aids.

The BSA says that a test is useful to diagnose CAPD if it is useful to diagnose neurological injuries.[3] In the comparison of patients with neurological lesions, cochlear lesions, and normal hearing,[41] PPS was a sensitive and specific test. Therefore, although the scientific evidence of this systematic review is already an empirical knowledge of some clinicians who work in the CAP evaluation area, it provides clear scientific subsidies. These allow the association of sensorineural hearing loss with the presence of CAPD in the clinical assessment of elderly people presenting performances lower than expected in PPS and/or DPS. This elderly person should be investigated for the presence of basic neurological changes that can be subclinical in this life cycle, with complaints related only to difficulties in hearing comprehension and speech recognition in noise.

On the other hand, there is a need to establish a reference percentage of correct answers for the elderly in both versions of the pitch and duration pattern tests. Studies that used the Auditec version of PPS showed lower than reference values (1430 and 880Hz)[39], although one of them did not show the type of response used.[39] In the Musiek version of PPS, scores were higher than the test reference (1122 and 880 Hz) in two of the three included studies[11,31] and below the reference in both groups in another study.[30]

Some study limitations should be mentioned. Variables such as gender, cognitive influence, and educational level must be evaluated so as to allow statistical comparison to verify their influence on test performance. Only one study had gender data.[29] Cognitive influences were analyzed in two of the included studies[11,30] through the Mini-Mental State Examination.[39] Educational level was analyzed by a study[11] that found no influence of this factor on DPS performance. Normative studies for these temporal tests also considered ecucational[13,19,20,24,27] and cognitive[21,49] influences. The BSA claims that CAPD is often found in conjunction with cognitive functions of language, speech, attention, executive functions, fluid reasoning, memory, and emotion and can impair these systems. Thus, CAPD can include auditory and cognitive elements.[2] No study aimed to verify correlations between PPS and cognition. Hence, further studies are needed to clarify the issue.

The number of presentations varied between studies in this review from 10 to 45. In other studies, this number varied from 15 to 60 for the elderly,[14,17] and as normative data for adults[20,22-24,27,43] in monoaural or binaural conditions. Musiek wrote a guide for the PPS test and stated that the test can be done with presentations ranging from 15 to 30 items in monoaural condition.[50] This shows the wide variety of application of these tests, leading to the need for studies that compare the different applications and their influence on the scores.

A descriptive study that measured the scores of elderly people with presbycusis for PPS and DPS did not observe influences of age or hearing loss.[26] As these studies did not have a control group to compare elderly people with presbycusis and normal hearing, the number of included studies decreased. Thus, there is a need to improve these tests for CAPD diagnosis[2] so that many studies can be compared and more consistent results can be obtained.

Although, initially, many studies seek the influence of age-related hearing loss on PPS and DPS, this review, following the eligibility criteria, included five studies, conducted in Brazil. Among the 10 studies excluded (Appendix 2) in phase 2 of this review, 9 were due to not having a comparative control group and/or not having the results of PPS and DPS in percentage of correct answers by groups, tasks, and/or ears (monoaural condition). Moreover, in phase 1, most of the excluded studies involving PPS and DPS in the elderly referred mainly to clinical or cross-sectional case studies aiming to describe the influence of neurological changes/injuries in these tests. In this context, the inclusion of exclusively national studies shows a difference between scientific interests in the use of these temporal processing testing protocols by the various research groups. Therefore, researchers in Brazil showed concern in designing studies that could in fact evidence the presence or not of differences in the performance of subjects of different ages and the influence of hearing loss on them.

The included studies also diverged in the number of items presented and in the test version, which modifies the frequency of stimuli in PPS or the duration of stimuli in DPS, a fact that prevented meta-analysis.

Such questions lead to the need for primary studies to improve the analysis of these variables that affect the universal applicability of these tests that show low influence of hearing loss in the elderly.

Conclusion

All studies in this systematic review did not show differences between elderly with hearing loss and normal-hearing elderly in PPS and DPS performance.

These findings allow us to infer that PPS and DPS can be applied in the context of clinical evaluation of auditory processing in elderly people with hearing loss, in which we can expect the same reference values of the elderly without hearing loss.

More primary studies using the same protocol as PPS and DPS are needed to create more consistent comparisons and conclusions, expanding generalization and thus increasing the level of evidence.

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Appendix 1. Database search strategy

Database	Search (May 13th 2018; updated on June 12th, 2020)
LILACS	(tw:("pitch pattern" OR "pitch patterns" OR "Pitch Perception" OR "Pitch Discrimination" OR "Pitch Discriminations" OR "duration pattern" OR "duration patterns" OR "frequency sequence" OR "frequency pattern" OR "frequency patterns" OR "temporal test" OR "temporal tests" OR "temporal auditory" OR "duration sequence" OR "PPS" OR "DPS" OR "FPT" OR "padrao de frequencia" OR "padrao de frequencia e duração" OR "padrao de duração" OR "padrao de duração e frequencia" OR "teste temporal" OR "testes temporais" OR "TPF" OR "TPD" OR "patrones de frecuencia" OR "patrones de duracion" OR "ordenamiento temporal" OR "pruebas auditivas" OR "prueba auditiva")) AND (tw:("auditory perceptual disorders"[MeSH Terms] OR "auditory perceptual disorders" OR "auditory perceptual disorder" OR "central auditory" OR "auditory processing" OR "Transtornos da Percepção Auditiva" OR "Transtorno da Percepção Auditiva" OR "processamento auditivo" OR "sistema nervoso auditivo central" OR "sistema auditivo central" OR "Trastornos de la Percepción Auditiva" OR "Trastorno de la Percepción Auditiva" OR "procesamiento auditivo" OR "sistema nervioso auditivo central")) AND (instance:"regional") AND (db:("LILACS"))
LIVIVO	("pitch pattern" OR "pitch patterns" OR "Pitch Perception" OR "Pitch Discrimination" OR "Pitch Discriminations" OR "duration pattern" OR "duration patterns" OR "frequency sequence" OR "frequency pattern" OR "frequency patterns" OR "temporal test" OR "temporal tests" OR "temporal auditory" OR "duration sequence" OR "PPS" OR "DPS" OR "FPT") AND ("auditory perceptual disorders" OR "auditory perceptual disorder" OR "central auditory" OR "auditory processing")
PubMed	("pitch pattern"[All Fields] OR "pitch patterns"[All Fields] OR "pitch perception"[MeSH Terms] OR "Pitch Perception"[All Fields] OR "Pitch Discrimination"[Mesh] OR "Pitch Discrimination"[All Fields] OR "Pitch Discriminations"[All Fields] OR "duration pattern"[All Fields] OR "duration patterns"[All Fields] OR "frequency sequence"[All Fields] OR "frequency pattern"[All Fields] OR "frequency patterns"[All Fields] OR "temporal test"[All Fields] OR "temporal tests"[All Fields] OR "temporal auditory"[All Fields] OR "PPS"[All Fields] OR "DPS"[All Fields] OR "FPT"[All Fields]) AND ("auditory perceptual disorders"[MeSH Terms] OR "auditory perceptual disorders"[All Fields] OR "auditory perceptual disorder"[All Fields] OR "central auditory"[All Fields] OR "auditory processing"[All Fields] OR "Auditory Diseases, Central"[Mesh:noexp])
Scopus	(TITLE-ABS-KEY("pitch pattern" OR "pitch patterns" OR "Pitch Perception" OR "Pitch Discrimination" OR "Pitch Discriminations" OR "duration pattern" OR "duration patterns" OR "frequency sequence" OR "frequency pattern" OR "frequency patterns" OR "temporal test" OR "temporal tests" OR "temporal auditory" OR "duration sequence" OR "PPS" OR "DPS" OR "FPT")) AND (TITLE-ABS-KEY("auditory perceptual disorders" OR "auditory perceptual disorder" OR "central auditory" OR "auditory processing")) AND (LIMIT-TO (DOCTYPE,"ar"))
SpeechBITE	"auditory processing"
Web of Science	("pitch pattern" OR "pitch patterns" OR "Pitch Perception" OR "Pitch Discrimination" OR "Pitch Discriminations" OR "duration pattern" OR "duration patterns" OR "frequency sequence" OR "frequency pattern" OR "frequency patterns" OR "temporal test" OR "temporal tests" OR "temporal auditory" OR "duration sequence" OR "PPS" OR "DPS" OR "FPT") AND ("auditory perceptual disorders" OR "auditory perceptual disorder" OR "central auditory" OR "auditory processing")
Google Scholar	("pitch pattern" OR "Pitch Discrimination" OR "duration pattern" OR "frequency sequence" OR "frequency pattern" OR "temporal test" OR "temporal auditory" OR "duration sequence") AND ("central auditory" OR "auditory processing")
Open Grey	("pitch pattern" OR "pitch patterns" OR "Pitch Perception" OR "Pitch Discrimination" OR "Pitch Discriminations" OR "duration pattern" OR "duration patterns" OR "frequency sequence" OR "frequency pattern" OR "frequency patterns" OR "temporal test" OR "temporal tests" OR "temporal auditory" OR "duration sequence" OR "PPS" OR "DPS" OR "FPT") AND ("auditory perceptual disorders" OR "auditory perceptual disorder" OR "central auditory" OR "auditory processing")
ProQuest	noft(("pitch pattern" OR "pitch patterns" OR "Pitch Perception" OR "Pitch Discrimination" OR "Pitch Discriminations" OR "duration pattern" OR "duration patterns" OR "frequency sequence" OR "frequency pattern" OR "frequency patterns" OR "temporal test" OR "temporal tests" OR "temporal auditory" OR "duration sequence" OR "PPS" OR "DPS" OR "FPT") AND ("auditory perceptual disorders" OR "auditory perceptual disorder" OR "central auditory" OR "auditory processing"))

Appendix 2. Excluded articles and reasons for exclusion

Excluded Studies	Reasons for exclusion
(Alonso 2011) (1)	4
(Asal et al. 2020 (2)	4
(Dias 2010) (3)	4
(Bellis and Wilber 2001) (4)	4
(Humes 1996) (5)	4
(Kumar and AV 2011) (6)	4
(Mukari, Umat et al. 2010) (7)	4
(Parra, Iório et al. 2004) (8)	4
(Rohini and Shany. 2018) (9)	1
(Sanchez, Nunes et al. 2008) (10)	4

Legend.
1- Adults under 60 years old;
2- History of language, learning, neurologic, or related disorders;
3- Electrophisiologic central auditory processing test; other temporal auditory that is not PPS or DPS tests;
4- Absence of comparison between groups with and without hearing loss, results not clearly described;
5- Reviews, letters, personal opinions, book chapters, and conference abstracts, case report, case series.

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Appendix 3. Risk of bias

Risk of bias assessed by Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI) critical appraisal tools. Risk of bias was categorized as High when the study reaches up to 49% score "yes", Moderate when the study reached 50% to 69% score "yes", and Low when the study reached more than 70% score "yes".

Analytical cross sectional studies

Question	Azzolini, Ferreira, 2010 (19)	Lima, Gonzale, 2016 (18)	Liporaci, Frota, 2010 (17)	Mesquita, Pereira, 2013 (20)	Peixe, Bruna, 2019 (32)
1- Were the criteria for inclusion in the sample clearly defined?	N	U	Y	U	Y
2- Were the study subjects and the setting described in detail?	U	U	Y	U	Y
3- Was the exposure measured in a valid and reliable way?	Y	Y	Y	Y	U
4- Were objective, standard criteria used for measurement of the condition?	Y	Y	Y	Y	Y
5- Were confounding factors identified?	N	Y	Y	N	Y
6- Were strategies to deal with confounding factors stated?	N	Y	Y	N	U
7- Were the outcomes measured in a valid and reliable way?	Y	Y	Y	Y	Y
8- Was appropriate statistical analysis used?	Y	Y	Y	Y	Y
TOTAL	50% M	75% L	100% L	50% M	75%L

Legend - Y=Yes, N=No, U=Unclear, L=low, M=moderate, H=high