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Review articles

Listening effort and working memory capacity in hearing impaired individuals: an integrative literature review

Laura Mochiatti Guijo[1]
Mirella Boaglio Horiuti[2]
Taina Maiza Bilinski Nardez[1]
Ana Cláudia Vieira Cardoso[1]

[1] Universidade Estadual Paulista Júlio de Mesquita Filho – UNESP – Marília, São Paulo, Brasil.
[2] Universidade Federal de São Paulo - Escola Paulista de Medicina – UNIFESP – EPM, São Paulo, São Paulo, Brasil.

Study carried out at the Course of Speech-Language Pathology and Audiology, Faculdade de Filosofia e Ciências, Universidade Estadual Paulista "Júlio de Mesquita Filho" – UNESP – Marília (SP), Brasil.

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Corresponding address:
Laura Mochiatti Guijo
Rua Guiro Shimabukuro, 106,
Parque das Acácias
CEP: 17510-050 - São Paulo, São Paulo, Brasil
E-mail: lauramochiatti@gmail.com

ABSTRACT

Purpose: to review the literature on the behavioral methods of listening effort assessment and the working memory capacity recommended for the hearing impaired.

Methods: this review was developed through the search of articles in national and international journals, in English and Portuguese, available in Pubmed/Medline, Cochrane Library, Biblioteca Vitual em Saúde – Literatura Latino-Americana e do Caribe em Ciências da Saúde (LILACS) and Scientific Electronic Library Online, between 2007 and 2017. The articles were selected based on the inclusion criteria: articles that used behavioral methods to assess listening effort in hearing-impaired adults, involving the measurement of working memory and its relationship with the listening effort, published in the last 10 years.

Results: Twelve articles in which behavioral measures were used to measure listening effort and working memory capacity in the hearing-impaired individuals were reviewed. Their main findings refer to the purpose(s) of the research, participants, behavioral method composed of a primary task (speech perception) and a secondary task (memorization) and results of the studies.

Conclusion: the findings of this review allow us to infer that this paradigm is sensitive to measure the listening effort, considering the different instruments used and the population assessed.

Keywords: Hearing Loss; Memory; Hearing Perception; Cognition

INTRODUCTION

In recent years, the number of studies, in the audiology field, which address the issue listening effort, has been growing. Authors report that there is still no consensus regarding the definition of listening effort, although it is often described as "the attention and cognitive resources necessary to understand speech", that is, it refers to the amount of perceptual, attentional and cognitive processing resources employed in the execution of a particular auditory task[1-4].

Due to this interest, many studies have been conducted with the purpose of improving the characterization of the listening effort and its assessment, mainly in the hearing-impaired population. The use of a reliable measure to assess this parameter would be invaluable in complementing the basic audiological assessment, as well as the speech perception tests performed in different listening conditions, silence and noise.

Authors claim that over the past two decades, the interest in auditory-cognitive interactions is of extreme relevance for hearing in general, and especially, for speech understanding in noise[5-7]. Some authors used in their study tests for the assessment of central auditory processing, which to a certain extent, they assess the auditory-cognitive interactions, such as the Dichotic Digit Test, as speech material for the measurement of the objective listening effort, with the recording of heart rate, skin temperature and conductance, and electromyographic activity of normal hearing individuals[8].

Although the research production related to the listening effort has increased, the progress in this area has been difficult due to the lack of consensus among researchers about methods of measuring listening effort and its validity as a measurable construct. The theoretical foundations and clinical applicability regarding listening effort are still unclear due to the immaturity of the research field and to the fact that the studies that investigate it use a variety of methodological procedures, including self-report, behavioral and physiological measures[3,4,9].

The behavioral measures, also titled as a dual-task paradigm, have been widely used to measure listening effort[10,11]. These assessment measures of the listening effort refer to the accomplishment of a recognition task of primary speech that occurs simultaneously with a secondary task. The secondary tasks refer to the visual reaction time (e.g., observing a visual stimulus and pushing a button) or recall (e.g., memorizing the heard speech). The difficulty of the primary task is systematically varied (e.g., sentence recognition at different noise levels or pseudo-words/logatome recognition).

The alteration in the performance of the secondary task, in the different levels of difficulty of the primary task, reflects a change in the cognitive resources for the speech processing, that is, the listening effort. This interpretation assumes that the performance on both the primary and secondary tasks requires the allocation of some common cognitive resources for each task. As the cognitive resources are limited, then greater listening effort and more cognitive resources will be required to the performance of the primary task.

For hearing impaired individuals, as the differences in the scores obtained in the speech perception tests in the noise as the differences in identifying the listening effort in types and levels of distinct noises have been associated with their working memory levels[12,13].

The dual-task paradigms have been used not only to investigate the listening effort itself, but also to investigate the effect of age, that is, the comparison of auditory performance and the effort discharged by young and old individuals when performing a task with different levels of cognitive demand and different signal-to-noise ratios; the effect of hearing loss, that is, the comparison of auditory performance and the effort discharged by normal hearing individuals and those with hearing loss, usually from mild to moderate degree, when subjected to the dual-task paradigms also with manipulation of signal-to-noise ratios and amount of cognitive demand employed; the effect of visual cues, where the authors investigated the amount of listening effort employed in auditory perception tasks and in auditory and visual perception tasks[14,15]; the amplification effect of the hearing aid[15-19], in which the noise reduction algorithms[20-23] have reduced the listening effort performed in an attempt to understand speech in everyday situations and in assessment. However, in the national literature, no studies were found that addressed this topic.

Therefore, the purpose of this study was to review the scientific literature regarding the behavioral methods for the listening effort assessment and the working memory capacity recommended for the hearing-impaired individuals. It is known that a more accurate understanding of how the different factors, such as the presence of hearing loss, the decrease in functionality caused by the aging process, the different speech stimuli used to measure the listening effort, in relation to the familiarity of the patient/participant with

the speech stimulus at the time of the assessment, the use of hearing aids with activated noise reduction algorithms, which interact to measure this effort, through behavioral methods can provide support to the intervention processes of hearing impaired patients with the aim of providing an improvement in the quality of life, especially in those who present cognitive decline due to the aging process.

METHODS

This literature review was developed through the search of articles in specialized national and international journals, both in English and in Portuguese languages, available in the following databases: US National Library of Medicine National Institutes of Health (PUBMED), Cochrane Library, Biblioteca Vitual em Saúde – Literatura Latino-Americana e do Caribe em Ciências da Saúde (LILACS) and Scientific Electronic Library Online (SCIELO).

The guiding question for the review was: "What instruments are used to assess listening effort and working memory capacity in a dual-task paradigm?". In order to obtain answers to this questioning, the research was carried out in stages, being the first the search of articles, in the mentioned databases, in a specific way in each database.

In order to collect the articles, the terms related to the "listening effort" were determined, found in the Descriptors in Health Sciences (Descritores em Ciências da Saúde - DeCS), in the Medical Subject Headings (MeSH) and, keywords related to the topic, combined with the use of the Boolean operators AND and OR. The terms chosen for the search were used in an isolated and crossed way (Figure 1). In all searches the "year of publication" and "word" filters were used.

Search number	Words and descriptors crossed
01	Hearing loss
02	Perda auditiva
03	Listening effort
04	Esforço auditivo
05	Ease of listening
06	Facilidade em ouvir
07	Cognitive load
08	Carga cognitiva
09	Processing load
10	Carga de processamento
11	Speech perception
12	Percepção de fala
13	Behavioral Assessment
14	Avaliação comportamental
15	Dual-task
16	Tarefa dupla

Figure 1. Relation of words and descriptors of topics used in the literature search

Initially, the inclusion or exclusion of articles was based on the information contained in the title and the abstract, but if this information was not conclusive, the article was read to fulfill the following inclusion criteria: articles that used behavioral methods, also called dual-task paradigm, to assess listening effort in hearing impaired adults, which involved the measurement of working memory and its relation to listening effort, published in the last 10 years, from 2007 to 2017. As exclusion criteria, articles about listening effort that included investigations with self-report and psycho-physiological methods, studies about listening effort assessment in populations without hearing loss, studies associated with hearing loss in children, articles for which only the abstract was available and, articles of literature review.

The analysis of the studies was initially carried out by reading the titles and abstracts, followed by a complete reading of the articles that fit the selection criteria. Each article was evaluated by one of the authors and, in case of uncertainty, there was a consensus among all authors in relation to the inclusion of the article.

The publications that were classified as eligible for this review, were read by at least one of the authors in order to extract the following information: authors and purpose of the research, participants, behavioral method used to evaluate primary task; behavioral method used to evaluate secondary task and, results of the studies. The mentioned characteristics of the selected studies were organized in a figure.

For the organization of the data, the articles that resulted from each crossed term were computed, which were repeated in relation to the previous search and that were related to the present study.

LITERATURE REVIEW

Nine hundred-eighty articles were found from the search carried out in the PUBMED/MEDLINE, Cochrane Library, LILACS and SCIELO databases, and each article had been presented in one or more databases. The selection process of the studies included in this literature review is explained in Figure 2.

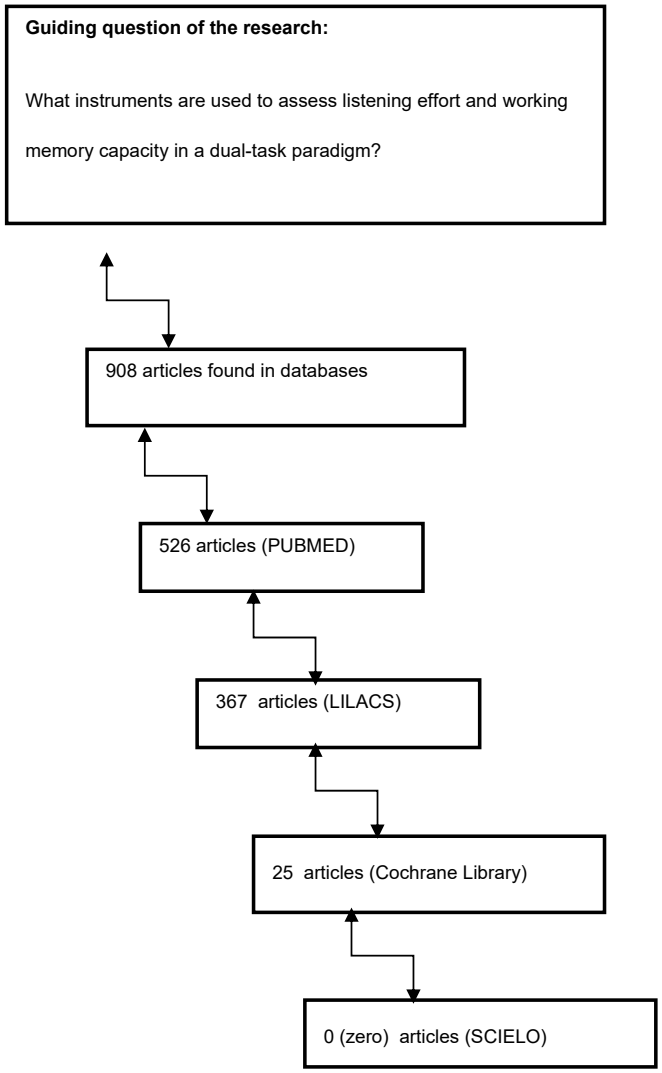

Figure 2. Selection process of the articles for literature review

In the reading of the abstracts of these articles, those that had previously been selected in other databases, those that did not fit the inclusion criteria, and the journals to which complete articles were not available during the search period. From this total, the abstracts were read, and 101 articles were selected. Of these, 29 articles were discarded because they did not include the inclusion criteria, 14 due to the unavailability of the complete texts, and 44 due to the duplicity in the consulted databases. After this detailed analysis, 12 articles were selected that met the established criteria for this review.

Authors (year) and purpose(s) of the research	Participants	Behavioral method used (primary task – speech perception)	Behavioral method used (secondary task – working memory capacity)	Type of auditory stimulus used in the dual-task	Results
(Tun; McCoy; Wingfield, 2009)[24] To investigate the effect of listening effort on recall of lists of words spoken by younger and older adults with good hearing and with mild to moderate hearing loss.	Participants were 48 individuals, subdivided into four equal groups. Each group consisted of 12 individuals according to the following criteria: age (young and old adults) and hearing acuity (normal hearing and mild to moderate hearing loss).	[1]Kent-Rosanoff Word Association Test: 24, lists of 15 words taken from words that share semantic associations.	[1]Recall lists of words of the Kent-Rosanoff Word Association Test. [2]Computerized search tracking (Visual tracking trials).	Lists of words were recorded by a female speaker of American English at a one-word rate every 3 seconds on the computer sound files at a sampling rate of 44,000 Hz.	The findings support the hypothesis that the extra effort at the sensory-perceptual level that accompanies the hearing loss has negative consequences for recall, an effect that may be aggravated by aging.
(Humes; Coughlin, 2009)[25] To examine the effects of increase of the processing load on the speech identification/ comprehension performance in closed set of adults and elderly as background noise with a background noise of one speaker.	[1]19 elderly individuals from 65 to 86 years, with sensorineural hearing loss at high frequencies; [2]10 adults with normal hearing, from 18 to 28 years old, assessed with the same spectral stimuli as the older adults; [3] Nine adults with normal hearing, from 18 to 28 years old who were assessed without spectral modeling.	[1]The Coordinate Response Measure (CRM) corpus.	[1]Working Memory Test (WMT). .	Six talker babble (the speech of six people, three men and three women).	Older adults/elderly people had poorer performance than younger adults, but also showed a decrease in relative improvement as far as the processing load decreased.
(Stewart; Wingfield, 2009)[26] To examine the intelligibility/audibility level functions for three types of speech materials by comparing psychophysical functions of the elderly with relatively good hearing with a group of individuals of the same age with mild to moderate hearing loss.	Participants were 48 individuals, subdivided into three groups: [1]16 undergraduate and postgraduate students of both genders, aged from 18 to 23 years, and normal hearing thresholds. [2]16 elderly individuals, of both genders, aged from 65 to 73 years, and normal hearing thresholds. [3]16 elderly individuals, of both genders, aged from 65 to 76 years, and with mild to moderate sensorineural hearing loss.	[1]Northwestern University Auditory Test No. 6. (NU-6). - Sentence Stimuli and Syntactic Complexity.	[1]Forward and backward digit span. [2]Digit symbols substitutions. [3]Trail Making Test Parts A and B. [4]Shipley vocabulary test.	Words and sentences were initially presented at the subliminal level, and then the intensity was increased in increments of 2 dB until the stimuli could be reported correctly.	The working memory resources were impacted by the cognitive resource demands required for the comprehension of syntactically complex sentences and for the effort caused by hearing loss.
Piquado; **Benichov**; **Brownell; Wingfield, 2012)[27]** To determine if the negative effects of hearing loss on the recall accuracy of spoken narrative skills can be minimized.	Participants were 24 adults, aged between 21 and 33 years old, subdivided into two groups according to hearing acuity. [1]12 adults with normal hearing acuity and [2]12 adults with mild to moderate hearing loss.	[1]Narratives with an extension paragraph, which should be recalled, presented in two listening conditions: with and without interruption.	[1]The participants were informed that they should remember aloud as much of the narrative as possible and, as accurately as possible.	All the narratives were presented through a computer sound file (sampling rate of 44,100 Hz) by an American English speaker, with a speech rate of 150 words per minute.	The results support the hypothesis that the listening effort associated to the reduction of hearing acuity may lengthen the processing operations and increase the working memory demand.

Authors (year) and purpose(s) of the research	Participants	Behavioral method used (primary task – speech perception)	Behavioral method used (secondary task – working memory capacity)	Type of auditory stimulus used in the dual-task	Results
(**Benichov; Cox; Tun; Wingfield, 2012)**[28] To examine the effects of age, hearing acuity, verbal ability and cognitive function on the use of the linguistic context in word recognition.	Participants were 53 adults, of both genders, aged between 19 and 89 years. The participants presented normal hearing acuity, mild hearing loss and moderate hearing loss. * English was the first Language spoken by all and they were in good health, with no history of neurological or vascular impairment.	[1]Short sentences in which the last word was masked by the babble Multi-talker babble. * The babble level was progressively reduced every 2 dB until the last word of the sentence could be identified.	[1]"Backward digit span" from the Wechsler Adult Intelligence Scale -III (WAIS).	Speaker of American English recorded on computer sound files at a sampling rate of 44,000 Hz.	The results showed that the capacity to use the linguistic context to aid the word recognition is robust enough.
(Rudner; Lunner; Behrens; Thore´n; Ronnberg, 2012)[3] To evaluate the relationship between subjective classifications of the effort involved in listening to speech in noise, speech recognition performance and working memory capacity of hearing aids with hearing loss.	Participants were 46 elderly individuals with mild to moderate bilateral hearing loss. In the first experiment, 16 Danish elderly individuals with a mean age of 63.5 years participated. In the second experiment 30 Swedish elderly individuals with mean age of 70 years participated.	First experiment: [1]Dantale II sentences. Listening effort was assessed in different signal-to-noise ratios. " Second experiment: [2]Hagerman sentences. Listening effort was assessed with a fixed level of noise".	Experiment 1: - Working memory capacity: [1]letter monitoring task. Experiment 2: Working memory capacity: [2]Reading Span Task. * A visual analogue scale was used for effort classification.	Modulated speech noise based on a modulation pattern of two interlocutors (two talkers). -Noise in the form of speech in steady state.	The subjective classifications of listening effort involved in speech recognition in noise are influenced by different signal-to-noise ratios, and the individual cognitive capacity seems to influence the classification in relation to the type of noise.
(Desjardins; Doherty, 2013)[29] To evaluate the relationship among cognitive function, listening effort and speech recognition in different listening situations in individuals with normal hearing and hearing loss.	Participants were 46 individuals: [1]15 young individuals (from 18 to 25 years old) with hearing thresholds within the normal range; [2]15 adults and elderly individuals (from 55 to 77 years old) with hearing thresholds equal to or less than 25 dB HL in the frequencies of 250 to 4000 Hz, bilaterally; [3]16 adults (from 59 to 76 years old) with bilateral sensorineural hearing loss, with hearing thresholds less than 75 dBHL, hearing aids users bilaterally for a period of at least six months.	[1]Revised Speech Perception in Noise Test (R-SPIN).	[1]The Digital Pursuit Rotor Tracking (DPRT) program. [2]Reading Span test. [3]Digit Symbol Substitution Test (DSST).	[1]Two-talker; [2]Six-talker, [3]Speech-Shaped Noise – (SSN).	Older adults need more cognitive resources than younger adults to understand speech with background noise.
(Picou; Ricketts; Hornsby, 2013)[15] To evaluate factors that influence the listening effort of people with hearing loss while processing the speech.	Participants were 27 adults, aged from 49 to 80 years, with mild to moderate bilateral sensorineural hearing loss, and hearing aid users for at least six months.	[1]Monosyllabic words spoken by a female speaker. [2] Press a button in response to a visual task.	[1]Automated Operation Span Task (AOSPAN).	Four talker-babble.	The results of this study suggest that, on average, hearing aids can reduce listening effort measured with the use of dual-task paradigms.
(Desjardins; Doherty, 2014)[23] To evaluate the effect of a noise reduction algorithm on listening effort in patients with hearing loss in a speech-in-noise task.	Participants were 12 hearing impaired elderly individuals, aged from 50 to 74 years, bilateral hearing aids users, with a fast-acting modulation algorithm based on noise reduction.	[1]Revised Speech Perception in Noise Test (R-SPIN).	[1]The Digital Pursuit Rotor Tracking (DPRT). [2]Reading Span test. [3]Digit Symbol Substitution Test (DSST).	Two-talker babble (TTB). .	The noise reduction algorithm reduced the listening effort in adults with hearing loss and should be used to improve speech comprehension in noise.

Authors (year) and purpose(s) of the research	Participants	Behavioral method used (primary task – speech perception)	Behavioral method used (secondary task – working memory capacity)	Type of auditory stimulus used in the dual-task	Results
(Heinrich; Henshaw; Ferguson, 2016)[30] To investigate the relationship between self-report and the behavioral measurement of speech perception in a group of individuals with hearing loss, HA users.	Participants were 30 individuals, aged between 50 and 74 years, with mild to moderate bilateral sensorineural hearing loss, hearing aids users for at least 3 months.	[1]Phoneme Discrimination (PD) test. [2]The Four Alternative Auditory Feature (FAAF) test.	[1]Letter Number Sequencing (LNS) task. [2]Size Comparison Span (SIC span). [3]Dual Task of Listening and Memory.	The speech stimuli were presented at an intensity of 65 dB SPL, in silence or with background noise (20 talker babble), in two signal-to-noise ratios: 0 dB and -4 dB.	The association between speech perception and cognition varied according to the tests used. The speech perception task associated with a memory task increases the listening effort.
(Bieber; Gordon-salant, 2017)[31] [1]To determine if a non-feedback training paradigm, including multiple speakers with various foreign accents, can facilitate the adaptation to a new accent for normal hearing adults and the elderly with and without hearing loss. [2]Determine whether there is retention of the benefit of training in the speech recognition performance and listening effort tasks.	The sample consisted of three groups of individuals [1]15 adults, from 18 to 28 years old, with normal hearing. [2]13 elderly individuals, from 65 to 76 years old, with normal hearing. [3]15 elderly individuals, from 70 to 82 years old, with mild to moderate sensorineural hearing loss.	[1]Hearing in Noise Test (HINT).	[1]Listening Span Test (L-SPAN).	Six talkers babble - native male speakers of English.	Although this non-feedback training paradigm for English with a foreign accent promoted good short-term adaptation for listeners, this is not enough to facilitate a lasting perceptual learning for participants.
(Shehorn; Marrone; Muller, 2018)[32] To compare the effectiveness of two fittings (prescription rules) of hearing aids, with and without non-linear frequency compression, marketed.	Participants were 17 adults, from 57 to 85 years of age, with symmetrical sensorineural hearing loss. * The tests were applied with participants wearing hearing aids fit with the prescription rule (NAL-NL2).	[1]Revised Speech in Noise Test (R-SPIN).	[1]Reading Span Test from Daneman and Carpenter.	Sentences presented with simultaneous babble noise. The sentences were presented at an intensity of 70 dBHL and the noise level was variable.	It was determined that individuals can benefit from non-linear frequency compression in speech recognition tasks in noise and reduct listening effort.

Legend: Hz = Hertz; HA = Hearing Aids; dB HL = Decibel Hearing Level; dB SPL = Decibel Sound Pressure Level.

Figure 3. Synthesis of published articles in which the behavioral method was used to measure listening effort and working memory of hearing impaired individuals (n = 12)

The synthesis of the articles, regarding the listening effort assessment and the working memory capacity, is presented in Figure 3.

The current article presents an overview of studies that used dual-task paradigms to assess the listening effort and the working memory capacity.

The purpose of this study was to describe the previous publications to provide an overview of the researches developed up to now, since the behavioral methods used to measure the listening effort are still little studied in the field of audiological research due to the viability and reliability of this method when compared to the assessment methods by means of the self-report of patients and also to the cost-benefit when compared to the psychophysiological assessment methods.

Specifically, this review aimed to describe the wide variety of methodological approaches that have been applied, especially the abundance of secondary tasks that use the working memory capacity to measure listening effort and; provide a broad summary of the results obtained.

Based on the analyzed studies, it was possible to infer that individuals who present some degree of hearing loss will dispense higher listening effort during the accomplishment of the dual-task paradigms[24], due to the audibility reduction and possible speech comprehension difficulties due to the injury of the peripheral and/or central auditory system. The relevance of investigation of the listening effort is intrinsically related to the complaints presented by hearing impaired patients, users or non-users of hearing aids, associated with reports of fatigue in speech comprehension situations, mainly in noise, or when the message is not familiar. Since only the auditory threshold measurement is not a good predictor in cases in which patients have difficulty understanding speech, because it portrays the auditory sensitivity and not the listening effort[24,28].

In the reviewed articles it is evident that the decline with age is related to the reduction of the working memory capacity, in this way, the older the individual, both the listener and the hearing-impaired individual, the lower their working memory capacity, and consequently the higher will be the listening effort dispended on speech comprehension tasks[25-29]. The hypothesis is that listeners with lower working memory capacity are more susceptible to the effects of background noise applied in tests that assess the listening effort[3,26,27].

In clinical contexts, speech comprehension is typically measured by the application of speech perception tests, calculating the proportion of correctly identified words under a particular listening condition, such as silence or noise, and the listening effort is an indirectly underestimated aspect. However, some authors[33] have proved that in individuals with hearing loss, users or non-users of electronic hearing devices, the recognition and understanding task of the acoustic signals is usually exhaustive, which justifies the assessment of this effort for the adequacy of the selection and adaptation process of hearing aids.

Other significant aspect is the influence of the speech stimulus complexity used in the dual-task and the different signal-to-noise ratios, both in the amount of listening effort and in the individual cognitive capacity, that is, in the working memory dispensed for the performance of the dual-task[3,26,27] and for the speech perception tests[28].

Authors have also demonstrated that in the fitting process of hearing aids, the noise reduction and non-linear frequency compression algorithms can reduce the listening effort employed as for the performance of the dual-task and as for the comprehension of the spoken message[15,23,32]. Although these aspects are used to reduce the listening effort during daily speech perception, little is known about techniques or therapeutic approaches to promote the reduction of this effort in the hearing-impaired individuals.

This literature review allows to highlight that the dual-task paradigm is an experimental procedure that seems to be sensitive to a series of differences in experimental conditions, both in the various groups of participants and intra-groups, and for this reason, systematic evaluations of the paradigms are needed to make decisions in relation to the study designs.

This analysis also revealed the lack of national studies that measure listening effort, especially with the use of dual-task paradigms. Given the importance of the cognitive processes involved in the speech perception process, it would be of great relevance to continuity of the investigations that contribute to the development of a clinical procedure that allows quantifying the listening effort in order to benefit the hearing-impaired individuals in the speech comprehension process in daily listening situations.

In summary, the present review may foster the interest of researchers in the listening effort measurement, through behavioral measures, especially the dual-task experimental paradigms.

CONCLUSION

This study presents a literature review on the behavioral methods of listening effort assessment, titled dual-task paradigms, and its relationship with working memory capacity in the hearing-impaired individuals, between 2007 and 2017. The findings of this review allow us to infer that the different behavioral methods used seem to be sensitive to a series of experimental conditions, such as: age of the participants, degree of hearing loss, type of noise used, type of speech stimulus used, memory capacity and hearing aids algorithms.

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