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Title: Auditory processing performance of the middle-aged and elderly: Auditory or cognitive decline?

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ABSTRACT

Background: Despite the well-established relationship between aging and auditory processing decline, identifying the extent to which age effect is the main factor on auditory processing performance remains a great challenge due to the co-occurrence of age-related hearing loss and age-related cognitive decline, as potential confounding factors.

Purpose: To investigate the effects of age-related hearing loss and working memory on the clinical evaluation of auditory processing of middle-aged and elderly.

Research Design: Cross-sectional study.

Study Sample: A total of 77 adults between the ages of 50 to 70 years were invited to participate in the study.

Data Collection and Analysis: The participants were recruited from a larger study that focused on the assessment and management of sensory and cognitive skills in elderly subjects. Only subjects with normal-hearing or mild-to-moderate age-related hearing loss, with no evidence of cognitive, psychological or neurological conditions were included. Speech-in-noise, dichotic digit and frequency pattern tests were conducted as well as a working memory test. The hearing loss effect was investigated using an audibility index, calculated from the audiometric threshold. The performance on the digit span test was used to investigate working memory effects. Both hearing loss and working memory effects were investigated via correlation and regression analyses, partialling out age effects. The significance level was set at $p < 0.05$.

Results: The results demonstrated that, while hearing loss was associated to the speech-in-noise performance, working memory was associated to the frequency pattern and dichotic digit performances. Regression analyses confirmed the relative contribution of hearing loss to the variance in speech-in-noise and working memory test to the variance in frequency pattern and dichotic digit test performance.

Conclusions: the performance decline of the elderly in auditory processing tests may be partially attributable to the working memory performance and, consequently, to the cognitive decline exhibited by this population. Mild-to moderate-hearing loss seems to affect the performance on specific auditory processing tasks, such as speech-in-noise, reinforcing the idea that auditory processing disorder in elderly might be also associated to auditory peripheral deficits.

Keywords: elderly, cognition, hearing

Abbreviations: DD: Dichotic digit, SN: speech-in-noise, FP: frequency pattern

INTRODUCTION

Research has demonstrated that as part of the natural aging process, elderly (Fitzgibbons and Gordon-Salantt,1996; Pichora-Fuller and Souza, 2003; Anderson et al, 2012; Moore et al, 2012; Fullgrabe, 2013; Schoof and Rosen, 2014) and occasionally middle-aged people (Grose et al, 2006; Moore et al, 2014) exhibit performance decline in tasks involving different auditory processing skills, such as speech perception in noise (Humes et al, 2013; Schoof and Rosen, 2014; Fullgrabe et al, 2015), temporal resolution (Pichora-Fuller and Souza, 2003; Gallun et al, 2014) and dichotic listening (Grose, 1996; Fullgrabe, 2013). Therefore, it is recommended a test battery for the diagnosis of auditory processing disorder, including speech-in-noise, auditory temporal and dichotic listening tests, in order to investigate the extent to which each specific auditory skill is impaired and how which skills should be addressed by rehabilitation.

Despite this well-established relationship between auditory processing decline and aging, identifying the extent to which the age effect is the main factor accounting for the degraded auditory processing performance remains a challenge due to co-occurrence of other confounding factors such as age-related hearing loss (Davis, 1991; Cruickshanks et al, 1998) and age-related cognitive decline (De Beni and Palladino, 2004; Craik and Rose, 2012; Grady, 2012). Moreover, several studies have noted the increased risk for co-occurrence of auditory disorders, such as presbycusis and auditory processing disorder, with cognitive decline, including mild cognitive impairment and even dementia (Peters et al, 1988; Baltes and Lindenberg, 1997; Avila et al, 2014; Panza et al, 2015; Wayne and Johnsrude, 2015) This co-occurrence highlights the difficulty in understanding sensory-cognitive interactions, particularly from the clinical perspective. Auditory sensory aspects that underpin the peripheral auditory function include pure-tone sensitivity as well as frequency selectivity, temporal coding fidelity, intensity resolution and loudness (Wayne and Johnsrude, 2015). Cognitive aspects that influence central auditory functions include different skills involving language, memory and other cognitive abilities such as general reasoning, processing speed, selective attention and other executive functions (Wayne and Johnsrude, 2015).

Several studies attempt to disentangle the effects of age and peripheral hearing loss on auditory processing by comparisons between age-matched groups of elderly with normal hearing and hearing impairment (Leigh-Paffenroth and Elangovn, 2011, John et al, 2102, Sheft et al, 2012) or by correlation between the audiometric results and the speech recognition performances in elderly groups (Cooper and Gates, 1992). The majority of these studies report detrimental effects of hearing loss on different aspects of auditory processing, such as temporal processing (Leigh-Paffenroth and Elangovn, 2011, John et al, 2012), dichotic listening (Cooper and Gates, 1992; Martin and Jerger, 2005) and speech recognition (Humes and Christopherson, 1991; Humes et al, 2013). However, for the majority of these studies, the co-occurrence of age-related cognitive decline, which may confound auditory processing test performance, has generally not been considered. Additionally, conflicting results regarding the age-related hearing loss effect have also been reported. For example, in a study by Sheft and colleagues (Sheft et al, 2012), the authors reported no difference between the performances of nine normal-hearing and nine elderly listeners with mild-to-moderate sensorineural hearing loss in tasks involving stochastic frequency modulation (FM) discrimination in background noise. The authors suggested that hearing loss distortion was not a factor that influenced the psychoacoustic performance of these listeners in this task.

Age-related cognitive decline is a well-known confounding factor for auditory processing performance, particularly because of the cognitive-sensory interaction that is observed with aging (Cohen, 1987; Humes et al, 2013; Moore et al, 2014; Fulgrabe et al, 2015). The cognitive aspect that frequently declines in the elderly and is most strongly associated with auditory processing performance is working memory (Pichora-Fuller et al, 1995; Hällgren et al, 2001; Pichora-Fuller, 2003; Akeroyd, 2008; Mukari et al, 2010). According to Pichora-Fuller et al (1995) working memory could be defined as a capacity-limited system in which information can be stored and manipulated using knowledge stored in long-term memory. Studies have demonstrated some degree of correlation between working memory performance and the perception of speech in noise (Pichora-Fuller et al, 1995; Akeroyd, 2008), pitch pattern frequency recognition (Mukari et al, 2010) and dichotic listening (Hällgren et al, 2001). However, conflicting results have also been reported (Mukari et al, 2010; Schoof and Rosen, 2014). For example, Mukari et al (2010) demonstrated a lack of correlation between working memory and the dichotic digit test performance of young and older groups when the variable age was controlled. Schoof and Rosen (2014) found that older adults experienced increased difficulties understanding speech only in the presence of two-talker babble; however, this finding was not associated with working memory performance, which suggests that the auditory processing performance was not explained by age-related cognitive decline involving working memory, specifically.

Although studies have demonstrated the effects of hearing loss and working memory on auditory processing performance, few have controlled both aspects in the same experiment. Such investigations are important because the greater the number of variables that are possibly involved in auditory processing performance, the greater the difficulty in interpreting the results of auditory processing evaluations. Moreover, experimental rather than clinical tests have generally been performed, which confounds the interpretation of the results from a clinical perspective. Therefore, in the present research, the auditory processing test performance of listeners with normal-hearing and mild-to-moderate age-related hearing loss was investigated. Dichotic digit, speech-in-noise and frequency pattern tests were included in the battery. Dichotic digit tests are good indicators of central auditory processing disorder (Musiek & Lamb, 1994; Bamiou et al, 2007; Bamiou et al, 2012), allowing the investigation regarding a specific aging process in the central auditory system. Speech-in-noise test was included because, in general, older adults report increased difficulties understanding speech in challenging listening conditions (Pichora-Fuller and Souza, 2003; Schoof and Rosen, 2014). As an auditory temporal processing test, the frequency pattern test is also important not only because of the possible age-related deficits in temporal processing (Humes et al, 2010; Gallun et al, 2014) but also because of the likely relationship between speech perception and temporal processing (Philips et al, 2000; Pichora-Fuller et al, 2007).

To investigate the hearing loss effect, an Audibility Index was calculated from the audiometric thresholds, based on the method described by Mueller and Killion (Mueller and Killion, 1990). This Audibility Index is a useful measure to scale hearing status numerically, allowing the investigation regarding the extent to which different degrees of hearing loss and others measures are correlated (Mueller and Killion, 1990). To investigate the cognitive effect, a working memory test (backward digit span) was conducted. This specific component of cognition was chosen because it is frequently reduced in the elderly and is strongly associated with auditory processing performance (Pichora-Fuller et al, 1995; Hällgren et al, 2001; Pichora-Fuller, 2003; Akeroyd, 2008). The recruited individuals were at least 50 years old or older and the auditory processing tests were those commonly performed in a clinical battery, such as speech-in-noise perception, pitch (frequency) pattern and dichotic digit tests.

We predicted that both age-related hearing loss and working memory would impact negatively on the performance on auditory processing tests. Additionally, we predicted the presence of significant sensory-cognitive interaction. From a clinical perspective, we expect the results to contribute to improving the understanding of the diagnoses of auditory processing disorder in middle-aged and elderly populations.

METHODS

Ethics Statement

This study was conducted at the Department of Physical Therapy, Speech-Language Pathology and Occupational Therapy of the School of Medicine at the University of Sao Paulo and was approved by the Research Ethics Committee of the Analysis of Research Projects of the University Hospital Medicine School, University of São Paulo under protocol number CEP-HU/USP: 100511 0 -SISNEP CAAE: 0034.0.198.000-10. A written consent form with detailed information about the aim and protocols of the study was also approved by this ethics committee.

Participants

A total of 77 adults, native Brazilian Portuguese-speakers, between the ages of 50 to 70 years took part in the study. Participants were selected from a large epidemiological study “Aging Maintaining functions: elderly in the 2020s” (Mansur and Carvalho, 2013) that focused on the assessment and rehabilitation of sensory and cognitive skills in elderly. All were recruited from the general community by flyer and advertisement posted in public spaces in the city of São Paulo. From this large study, participants were selected based on the inclusion criteria of having no evidence of cognitive, psychological or neurological conditions, investigated by psychologists and neurologists. In terms of cognition, in order to exclude the presence of cognitive impairments, the participants were required to attain the following cut-off scores, adapted to the subjects' educational level, on the Mini-Mental State Exam (MMSE): >25, >26, or >28 for 1 to 4 years, 5 to 8 years, and more than 9 years of formal schooling, respectively (Folstein et al, 1975; Bruck et al, 2003). In addition, they were also required to not exceed a score of 2 points on the Questionnaire of Cognitive Change (QMC8) (Damin and Brucki, 2011) and a score of 7 points on the Functional Assessment of Communication Skills for Adults (ASHA-FACS) (Carvalho and Mansur, 2008). Neurological and psychological aspects were investigated using the Geriatric Depression Scale-15 (Sheikh and Yesavage, 1986; Almeida and Almeida, 1999). In terms of hearing evaluations, the participants underwent otoscopy and audiological assessments including pure-tone threshold audiometry and a speech recognition threshold (SRT) test. Both tests were administered in a Siemens sound-proof booth, calibrated in accordance with ANSI S3.1, using a GSI-61 two-channel clinical audiometer, also calibrated in accordance to ANSI S3.6, used with TDH39 earphones. Normal-hearing listeners and listeners with mild-to-moderate age-related hearing loss were included. Normal hearing was defined as pure-tone threshold audiometry ≤ 25 dB HL for octave frequencies from 250 to 8000 Hz and the mild-to-moderate age-related hearing loss was defined as bilateral, symmetrical and sloping hearing loss (pure-tone thresholds ranging from 25-70 dB HL at least at the frequencies of 3 kHz to 8 kHz). Because most of the auditory processing tests had to be performed at the level of 50 dB SL above speech recognition threshold (SRT) (Jerger and Musiek, 2000), individuals with severe hearing loss were not included.

The participant characteristics, such as age, educational level and cognitive screening performance are illustrated in Table 1.

(Table 1)

Procedures and Measures

After signing the written consent forms, the subjects underwent all auditory processing tests (i.e., the dichotic digit, frequency pattern and speech-in-noise tests) as well as the working memory test. The tests were chosen as recommended by the American Academy of Audiology (2010) for the diagnosis of auditory processing disorder. Moreover, accounting for the clinical purpose of this study, only tests that had been standardized for the Brazilian population were included. To investigate the influence of age-related hearing loss and working memory on the auditory processing performance, the hearing loss was scaled using the Audibility Index (AI) and the working memory was assessed using a digit span test.

Auditory Processing Tests

All auditory processing tests were administered in a sound-proof booth using a GSI 61 Audiometer, Sony Compact Disc Player and headphones. The stimuli, recorded on a compact disc, were played on the CD player connected to the audiometer. This audiometer controlled the stimuli intensity at a fixed level of 50 dB SL in reference to the SRT.

Dichotic digit test (DDT) (Pereira and Schochat, 1997)

This central auditory test assesses binaural integration skills (i.e., the ability to process different stimuli that are presented simultaneously to each ear). This Brazilian version of the dichotic digit test was composed of naturally spoken dissyllabic digits with similar syllable lengths; specifically, 4, 5, 7, 8, and 9 were used. The digits were spoken in Portuguese by a male speaker. The test included 20 trials. Each trial consisted of 2 pairs of digits presented simultaneously (with one pair of the two routed to each ear). The individual was instructed to listen carefully and repeat the both pairs of digits at the end of each trial. In total, the test included 40 pairs of digits (80 digits per ear). Performance was scored according to the percentage of correctly repeated digits in each ear, irrespective of the order.

Speech-in-noise test (SNT) (Pereira and Schochat, 1997)

This central auditory test assesses the ability to understand speech in a background of noise. This Brazilian version of the speech-in-noise test was composed of 25 monosyllabic words spoken in Portuguese by a male speaker that were presented to each ear at a fixed signal-to-noise ratio of +20 dB. The background noise was white noise. The individual was instructed to carefully listen to each of the words and then repeat them. Performance was measured according to the percentage of correctly repeated words that were presented to each ear. This test was administered in a sound-attenuating booth at 50 dB SL relative to the SRT.

Frequency pattern test (FPT) (Musiek and Pinheiro, 1987)

This central auditory test assessed skills related to auditory temporal processing (i.e., the ability to process nonverbal auditory signals and recognize the order or pattern of the presentation of these stimuli). This test consisted of 20 trials with approximately 6-sec intertrial intervals. Each trial included three stimuli of 150 ms in duration and an interstimulus interval of 200 msec. The low stimulus (L) was 880 Hz, and the high stimulus (H) was 1122 Hz. The individual was instructed to carefully listen to all three stimuli and to respond by naming them in the order in which they were presented (e.g., "low, low, high", "high, low, low", etc.). Performance was measured according to the percentage of correct trials. This test was administered diotically in a sound-attenuated booth at 50 dB SL relative to the SRT.

Working memory test

Digit span (backward recall) (Wescher, 1987)

This test was taken from the WAIS (Wechsler Adult Intelligence Scale) test to investigate the extent at which auditory processing and cognitive performance were associated. In this working memory test, participants were instructed to verbally repeat a sequence of numbers, also presented verbally, in the reverse order. The number of digits in the sequence was gradually increased until the participant could not repeat them correctly. The digit span performance was taken as the number of digits for the longest list of numbers repeated accurately.

Audibility Index

The Audibility Index is a useful measure to scale hearing status numerically, and thus facilitate correlational analysis for degree of hearing loss and others measures. The calculation method was described by Mueller and Killion, 1990 and used in a previous study (John et al, 2012). The index is calculated on the basis of the air-conduction thresholds and using the count-the-dot method, in which different frequencies are weighed according to their importance for understanding speech. This index number thus indicates the audibility of a typical speech signal for the measured ear and ranges from 0 to 1.0.

Statistical analyses

The data were analyzed using SPSS version 22.0. Pearson´s correlation and stepwise multiple regression were calculated to determine the strength of the association between hearing loss, working memory and auditory processing performance. More details about each analysis are described further. The significance level was set at $p < 0.05$.

RESULTS

Correlations between auditory processing, working memory and hearing loss.

Performance results for the auditory processing and working memory tests, as well as the audibility index for each ear, are listed in Table 2.

(Table 2)

First, the association between these performances was assessed to investigate the extent to which the performances on auditory processing tests were associated to either working memory performance or hearing loss. The correlation between auditory processing test performances and working memory was assessed, partialling out the effect of age, gender, education and hearing. The correlation between auditory processing performances and hearing loss was assessed, partialling out the effect of age, gender, education and working memory. Significant correlation coefficients ($p < 0.05$) are shown in black in Table 3.

(Table 3)

Dichotic digit test

Partial correlations showed a weak to moderate association between digit span performance and the right ear on dichotic digit [$r_{partial}$ = 0.30, p<0.01] and a tendency toward significance association between digit span and the left ear [$r_{partial}$ = 0.20, p=0.09]. No significant correlations were observed between audibility index and dichotic digit test performance.

Speech-in-noise test

No significant correlations were observed between the speech-in-noise (both ears) and digit span tests (see Table 3). Regarding hearing loss, partial correlations showed a moderate association between audibility index in the right ear and speech in noise performance in this same ear [$r_{partial}$ = 0.49, p<0.01]. The same results were obtained between the audibility index in the left ear and speech-in-noise performance in this same ear [$r_{partial}$ = 041, p<0.01]. A weak to moderate association was found between audibility index and speech-in-noise performance; audibility index (left ear) and speech-in-noise (right ear) [$r_{partial}$ = 034, p<0.01] and audibility index (right ear) and speech-in-noise (left ear) [$r_{partial}$ = 038, p<0.01].

Frequency pattern test

Partial correlations showed a moderate association between performance on the digit span and frequency pattern test [$r_{partial}$ = 0.43, p <0.001]. No significant correlations were observed between audibility index and frequency pattern test performance.

Figure 1 shows the significant correlations between the audibility index and speech-in-noise performance in both ears. Figure 2 shows the correlations between working memory and frequency pattern as well as working memory and dichotic digit performance in the right ear. The figures also show the significant coefficients for the whole group.

(Figure 1 and 2)

To investigate sensory-cognitive interactions, the strength of the association between working memory and hearing loss was also assessed, partialling out age and education. No significant correlation was observed between audibility index and digit span performance.

Stepwise multiple regression

Multiple regression analyses (stepwise method) were performed to investigate the relative contribution of hearing loss and working memory to the variance in the auditory processing tests. Audibility index, working memory and also age were considered as predictor variables.

For the speech-in-noise performance in the right ear, the model that explained the highest percentage (18%) of the variance was based on only the audibility index in the same ear [F (1, 76) = 16.6, p<0.001]. The standard regression coefficient was 0.42 (p<0.001). For the speech-in-noise performance in the left ear, the best model also included audibility index in the same ear as best predictor, which explained 16% of the variance [F (1, 76) = 14.3, p<0.001]. The standard regression coefficient was 0.40 (p<0.001).

For the frequency pattern performance, the best model included working memory as best predictor, which explained 17% of the variance [F (1, 73) =14.7, p<0.001]. The standard regression coefficient was 0.41 (p<0.001). Working memory was also the best predictor for the dichotic digit test in the right ear, but explaining only 7% of the variance [F (1, 76) = 5.89, p = 0.01]. The standard regression coefficient was 0.27 (p=0.01).

For the dichotic digit performance in the left ear, working memory, hearing and even age did not significantly contribute to variance on performance.

DISCUSSION

The main purpose of the present research was to investigate the effects of age-related hearing loss and working memory on the auditory processing performance of middle-aged and elderly subjects to better interpret the results of auditory processing evaluations. The results demonstrated that hearing loss was associated to the speech-in-noise test performance, while working memory was associated with the frequency pattern and dichotic digit test performance. No association was found between hearing loss and working memory. The average test scores of the group, although high, were slightly below the expected average scores for young Brazilian adults (Pinheiro and Schochat, 1997). Mean test score are reported to be 95% in each ear in the dichotic digit test, 70% in the speech-in-noise test and 75% in the frequency pattern test. Previous studies have also demonstrated that the performance of older adults on dichotic digit (Luz e Pereira, 2000), frequency pattern (Parra et al, 2004) and speech-in-noise (Pereira and Schochat, 2011) tests are below the performance of young individuals. This finding is consistent with previous research, reinforcing the idea that the decline presented here was associated with aging. The observation of only a slight decline was potentially due to the inclusion of middle-aged individuals, who might still have demonstrated good performance on the clinical auditory processing tests.

The effect of hearing loss on the speech-in-noise test performance corroborates several studies' findings (Humes and Christopherson, 1991; Cooper and Gates, 1992; Martin and Jerger, 2005; Leigh-Paffenroth and Elangovn, 2011, John et al, 2012; Humes et al, 2013) and also supports the peripheral hypothesis regarding the auditory processing difficulties of the elderly (Humes et al, 2012). According to this hypothesis, auditory difficulties, such as those related to understanding speech in background noise and discriminating temporal changes in auditory stimuli, are predominantly the consequence of the loss of audibility associated with age-related hearing loss. Thus, loss of hearing can lead to an interaction between central and peripheral auditory deficits. Additionally, research has also demonstrated that the hearing loss effect might be more prominent for some specific auditory tasks vs. others (Humes et al, 2012; Sheft et al, 2012). For example, in an extensive review of central presbycusis, Humes et al (2012) concluded that hearing loss generally has greater influences on auditory test measures that involve understanding speech than on tasks involving nonspeech stimuli, such as demonstrated in the present research. The explanation for this observation is that the broadband nature of speech signals requires reasonable audibility over at least 4000 Hz for discrimination (Humes et al, 2012). In contrast, nonspeech stimuli are easier to discriminate if they are composed of frequencies in the range of normal hearing. For example, Sheft and colleagues (2012) reported no hearing loss effects on a task involving the discrimination of frequency modulations (FMs), with a carrier frequency of 1 Khz presented in background noise for elderly listeners with normal hearing or a mild-to-moderate sensorineural hearing loss. Similarly, in the present study, the frequency pattern test included low and high stimuli at frequencies of 880 Hz and 1122 Hz, respectively. Similarly, in the present study, the lack of a hearing loss effect on the nonverbal tests might be explained by the presence of normal hearing (or only a mild hearing loss) in the frequency range of the test stimuli. Therefore, the present results confirmed that hearing loss might affect the performance in tests involving speech recognition in a background noise, probably due to broadband nature of speech signals. From a clinical perspective, these results suggest that auditory processing test deficits in the middle-aged and elderly with mild-to-moderate hearing loss might be associated with auditory peripheral deficits.

Working memory effects were observed in the frequency pattern and dichotic digit tests. Additionally, a stronger correlation was observed between the working memory and Frequency Pattern Tests (r =0.43) than between the working memory and dichotic Digit tests (r = 0.30), which suggests that the cognitive demand in the Frequency Pattern Test was probably greater than that in the dichotic digit test. The Frequency Pattern test requires the individual to not only carefully attend to the sounds but also to associate each sound with an oral response, stored within memory, and act on the association when speaking the correct answer (Moore, 2012). Thus, this association between sound and oral response probably explains why a stronger correlation was observed in the Frequency Pattern test than the dichotic digit test, the latter of which does not require such associations. Additionally, in the frequency pattern test, the individual is also required to memorize the stimuli sequence in order to respond correctly, while in the dichotic digit test the individual can repeat irrespectively of the order, which probably reduces the cognitive demand of the test.

Mukari et al (2010) also observed an association between temporal ordering and working memory performance. As in the present study, these authors reported a moderate correlation between the performances in the digit span test and the Pitch Pattern Sequence test. The authors point out that a positive correlation between working memory is expected as the correct response on the Frequency Pattern test is scored on the correct labelling of the tonal sequence. Mukari et al explain in detail how interpretation of patterns and identification occur in the right hemisphere and then this tonal sequence must be conveyed to the left hemisphere via the corpus callosum where verbal labeling takes place. Thus the test is less related to specific auditory modality.

Mukari et al (2010) also investigated the correlations between performance on the Dichotic Digit Test and working memory among older adults. Contrary to the present findings, these authors observed no correlation between Dichotic Digit Test and working memory when the effect of age was partialized out. Hallgren et al (2001) demonstrated a correlation between the performance in the digit span test and a free-report condition of the dichotic digit test in the elderly; however, their results were also associated with an effect of age. This cognitive influence on dichotic listening test performance has been extensively studied by Hughdal and colleagues in children and young adults (Hugdahl and Anderson, 1986; Hugdahl et al, 2001; Hugdahl, 2003), and the results have demonstrated greater cognitive engagement in the forced-left condition that is produced by competition with the 'right ear advantage'. In the present study, after controlling for an age effect, a cognitive effect was observed even in the free recall condition, albeit this effect is only weak-to-moderate (r =0.30) in the right ear and with tendency to significance in the left ear (r = 0.20, p = 0.09). Therefore, from a clinical perspective, in addition to ageing effects, the performance of the middle-aged and elderly in the Frequency Pattern and dichotic digit tests might be also associated, at least partially, with some degree of cognitive decline rather than with pure age-related auditory processing decline.

In the present study, we also observed a lack of association between working memory and the performance on the speech-in-noise test. Current findings are consistent with previous work investigating associations between working memory and speech perception in noise (Schoof and Rosen, 2014). Indeed, in this study, no association was found between performance of elderly individuals on working memory and speech perception tasks for words in the presence of two-talker babble. These results suggest that age-related cognitive decline, involving specifically working memory, does not necessarily lead to speech-in-noise problems. However, association between working memory and speech perception in noise has also been reported (Pichora-Fuller et al, 1995; Akeroyd, 2008). Pichora-Fuller and colleagues (Pichora-Fuller et al, 2003) hypothesized that, as a consequence of hearing difficulties and the effort required to listen in the presence of noise, the efficient operation of the working-memory system becomes compromised and negatively affects the comprehension of spoken language. Perhaps the controversies regarding the influence of working memory on speech perception are related to the type of speech that is utilized in the noise task because more complex speech perception tasks might demand more cognitive engagement. Thus, tasks involving single words, such as those used in the present research, are likely less cognitively demanding than tasks that involve sentences, such as those used in the study by Pichora-Fuller and colleagues (1995). From a clinical perspective, the absence of working memory effects on the speech-in-noise task performance indicates that the worse performance exhibited by the elderly might likely be interpreted as a result of elevated thresholds and not attributable to cognitive changes.

Previous research has shown a strong connection between age-related decline in working memory and problems with auditory performance (Peters et al, 1988; Baltes and Lindenberg, 1997; Panza et al, 2015; Wayne and Johnsrude, 2015). No association was found in the current study between working memory and the audibility index. Perhaps this lack of interaction was due to the fact that only one specific component of cognition was assessed (working memory).Thus, further studies should investigate sensory-cognitive interaction using additional cognitive measures. Another hypothesis is related to the level of hearing loss and subject selection methods. Perhaps a mild to moderate hearing loss may not be sufficient to be associated with working memory performance.

Few studies have investigated the effects of age-related hearing loss and working memory on auditory processing test performance in the same study. The present results demonstrated that even after controlling for age, performance on the auditory processing tests, such as the Frequency pattern and dichotic digit tests, was affected by an aspect of cognition while speech-in-noise test performance was affected by hearing levels. Our results demonstrated that from a clinical perspective, the poor performances of older adults in tests of auditory processing might not be specifically attributable to auditory recognition and processing decline specifically. Poor performance might be partially attributable to working memory limitations and consequently to the cognitive decline exhibited by this population. Mild-to moderate-hearing loss, seems to affect the performances on specific auditory processing skills, such as speech-in-noise, reinforcing the idea that auditory processing disorder are also linked to auditory peripheral deficits in elderly.

Since the present results demonstrate that some clinical auditory processing tests show high cognitive demand, a careful evaluation of elderly subjects cognitive skills, such as working memory, is essential before interpreting their performance on auditory processing tests. Additionally, both the degree and configuration of the hearing loss must also be taken into consideration especially when considering results of auditory processing tests involving verbal stimuli. Further studies should focus on the development of clinical auditory processing tests with low cognitive demand to reduce the impact of confounding factors such as age-related cognitive decline.

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