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Original Article

Does Asymmetric Hearing Loss Affect the Ability to Understand in Noisy Environments?

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OBJECTIVES: This study aimed to determine whether, in asymmetric hearing loss, the presence of an ear with a better or worse hearing threshold is related to either better or worse speech-in-noise (SiN) intelligibility.

MATERIALS and METHODS: A total of 618 subjects with different degrees of hearing loss were evaluated for their ability to understand SiN. A stepwise forward logistic regression analysis was performed to identify the factors that affect performance. The influencing factors of very high or very low performance were determined.

RESULTS: Age, especially after 70 years of age, and hearing loss, especially from moderate hearing loss, negatively influence SiN intelligibility. Remarkably high intelligibility was identified in subjects with a contralateral ear presenting a better auditory threshold.

CONCLUSION: Although age and hearing loss are known factors that affect SiN intelligibility, the presence of a healthy contralateral ear is presented as the first description of preservation of SiN hearing ability.

KEYWORDS: Noise, hearing loss, unilateral,

INTRODUCTION

The harmful effects of noise on communication are well known [1]. They may cause both work and personal after-effects. Noise is a constraint in speech processing, which becomes especially important in subjects with hearing loss [2], since auditory speech processing becomes challenging in this population [3]. Whilst some research has been carried out on the speech-in-noise (SiN) hearing ability in humans, few studies have recruited a large sample of patients, which limits their conclusions.

Although age [4] and co-occurrence of age-related cognitive decline [5] are known factors that affect SiN intelligibility, the effect of asymmetric hearing loss, either improving or worsening SiN hearing ability, has not been studied.

This study aimed to determine in a large sample of patients whether, in asymmetric hearing loss, the presence of an ear with a better or worse threshold is related to either better or worse SiN performances.

MATERIALS AND METHODS

This observational descriptive study was conducted in a tertiary hospital, with a sample of 618 subjects. Recruitment of subjects was carried out over three years, and a trained audiologist performed the audiological tests. Eligibility criteria were broad; subjects complaining of hearing loss of any origin were recruited from the general consultation of five otolaryngologists. Recruitment was sequential, and all subjects who agreed to participate in the study were tested on the same day of diagnosis of hearing loss.

The minimum sample size was determined such as to allow comparisons of multiple means. Considering that there were five groups (normal hearing plus four grades of hearing loss), an alpha value set at 0.05, a beta value set at 0.2, and an expected effect size around 0.5, the

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minimum required sample of subjects is 480. Recruitment was extended every one year, until by the end of the third year the sample size had been satisfied, and the statistical analysis of the data could be started.

The 618 patients with hearing loss were classified according to the criteria of the World Health Organization [6]; averages of values at 500, 1000, 2000, and 4000 Hz were used to determine the grade of impairment. Asymmetric hearing loss was defined as a difference of 15 dB HL between ears at three contiguous frequencies.

The institutional ethics committee approved this study. All patients gave their informed consent to participate in this study.

Hearing assessment was made using an Audiotest300 (Interacoustics, Middelfart, Denmark). The SiN test was performed using the Santiago APD monosyllable package, which has been validated in Spanish [7] and is distributed by AudioTEC (St. Louis, MO, USA). Words were presented 40 dB above the threshold determined with the frequencies 500, 1000, and 2000 Hz; and a white noise was used 50 dB above this same threshold. For masking in subjects with asymmetric hearing loss, a white noise 30 dB HL above the auditory threshold was used in the contralateral ear. A noise level of 100 dB was never exceeded, regardless of the auditory threshold of the subject. The percentage of correct answers was determined with the number of correct words that the subject manages to repeat out of 25 words presented in each ear.

This study was conducted following the STROBE guidelines recommended for observational studies [8].

Statistical Analysis

As age, sex, and auditory threshold were possibly related to SiN intelligibility, a stepwise forward logistic regression analysis was performed to identify their corrected effect. Logistic regressions are used to obtain odds ratios in the presence of more than one explanatory variable, which obtains the impact of each variable on the odds ratio of the observed event of interest [9]. By analyzing the association of all variables together, confounding effects are avoided.

Once this was done, a curve fitting was performed using the Boltzmann method, to determine the expected percentage of correct answers with respect to the auditory threshold. Subjects who presented unusually high percentages (above the prediction band) or unusually low percentages (below the prediction band) were identified and compared with subjects who were within the prediction band.

Given that this study aimed to determine if asymmetric hearing loss is associated with a change in SiN intelligibility, the comparison of out-of-range subjects was made looking for differences in frequency of asymmetric hearing loss, as well as in age and sex. Age data were compared using the Mann–Whitney rank sum test, and data relating to sex and frequency of asymmetric hearing loss were compared using the Z-test. Data obtained were analyzed using the statistical program SigmaPlot (Systat Software; San Jose, CA, USA). The curve fitting analysis was performed with OriginPro (OriginLab; Northampton, MA, USA).

RESULTS

A total of 618 individuals were studied. The number of subjects in each stage of the study (e.g. numbers potentially eligible, examined for eligibility, included in the study, completing assessment) and the reasons for non-participation in each stage are explained in Figure 1.

The mean age of the participating subjects was 67.1±14.6 years (range 18–95 years). A total of 298 individuals (48.2%) were men.

The main output data, that is, the audiometric threshold and the percentage of correct answers in the SiN test, have been reported separately for subjects with symmetric hearing loss (Table 1) and for subjects with asymmetric hearing loss (Table 2), as important differences in the percentage of correct answers were observed.

As multiple variables were studied in their ability to size up SiN intelligibility, a stepwise forward logistic regression analysis was performed to preclude the possible influence of confounding factors among these variables. As expected, only age ($p<0.001$, $R^2=0.279$) and hearing threshold ($p<0.001$, $R^2=0.232$) were actually affecting SiN intelligibility, while sex was not ($p=0.197$).

Table 1. Subjects with symmetric PTA (Pure-tone audiometry)

Subjects with	Age (mean±SD)	n (% of total)	Audiometric threshold (dB HL)	Speech-in-noise (%)
No impairment	53±17	35 (5.7%)	19.8±5.1	83.5±16.4
Symmetric slight HL[a]	67±14	141 (22.8%)	34.4±4.0	84.1±12.3
Symmetric moderate HL[a]	74±11	116 (18.8%)	50.4±5.9	68.5±24.7
Symmetric severe HL[a]	78±10	19 (3.1%)	68.9±4.7	40.3±25.5
Symmetric profound HL[a]	69±10	2 (0.3%)	87.5±2.9	0.0±0.0

[a]HL: hearing loss

Table 2. Subjects with asymmetric PTA (Pure-tone audiometry)XXX

			Audiometric threshold (dB HL)		Speech-in-noise (%)	
Subjects with	Age (mean±SD)	n (% of total)	Best ear	Worst ear	Best ear	Worst ear
No impairment in best ear	63±13	96 (15.5%)	22.1±3.7	43.0±12.1	89.9±10.5	86.4±11.2
Asymmetric, slight HL[a] in best ear	68±12	138 (22.3%)	36.2±4.0	53.0±13.2	82.0±16.1	79.5±19.4
Asymmetric, moderate HL[a] in best ear	72±13	50 (8.1%)	52.3±6.0	71.9±11.7	72.0±22.3	59.9±28.6
Asymmetric, severe HL[a] in best ear	58±20	5 (0.8%)	69.0±2.2	96.2±24.7	44.0±35.3	33.6±35.3
Single-sided deafness	64±17	16 (2.5%)	25.5±6.7	81.3±17.3	80.4±23.8	75.3±23.8

[a] HL: hearing loss

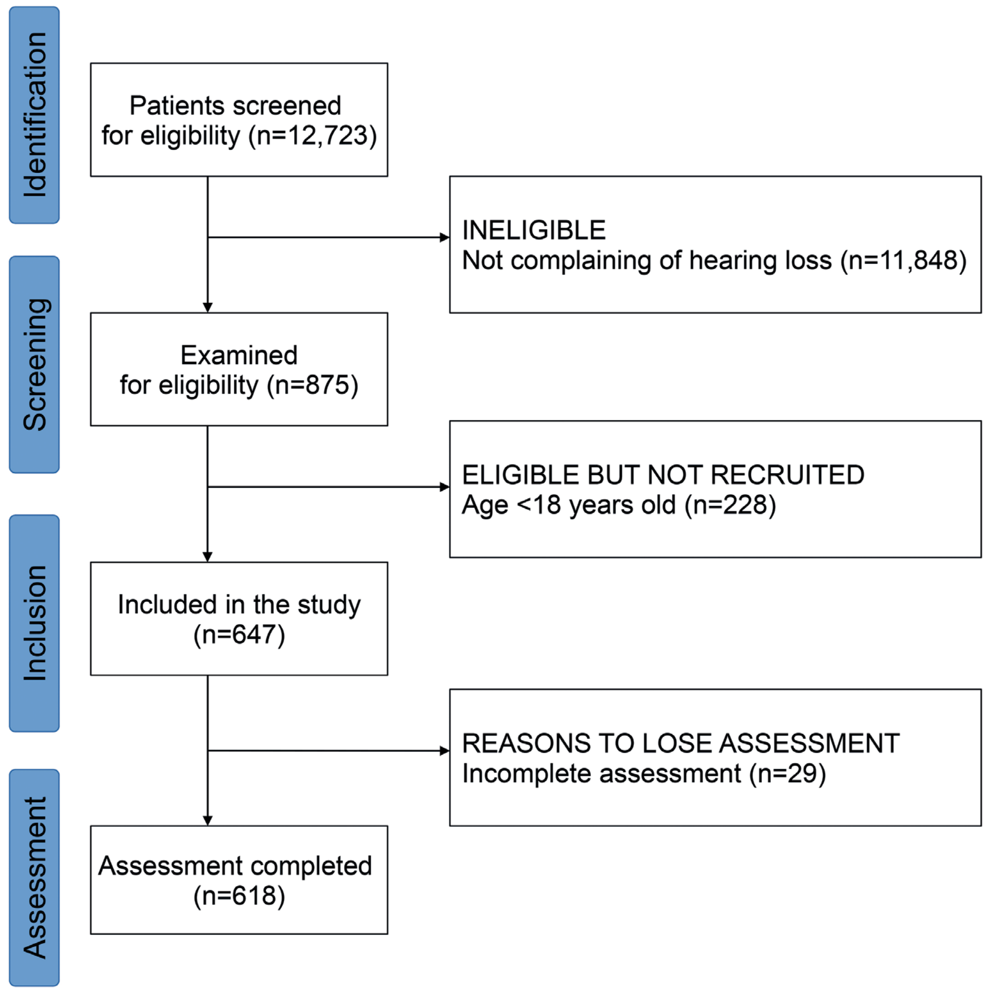

Figure 1. Flow diagram reporting numbers of individuals at each stage of study.

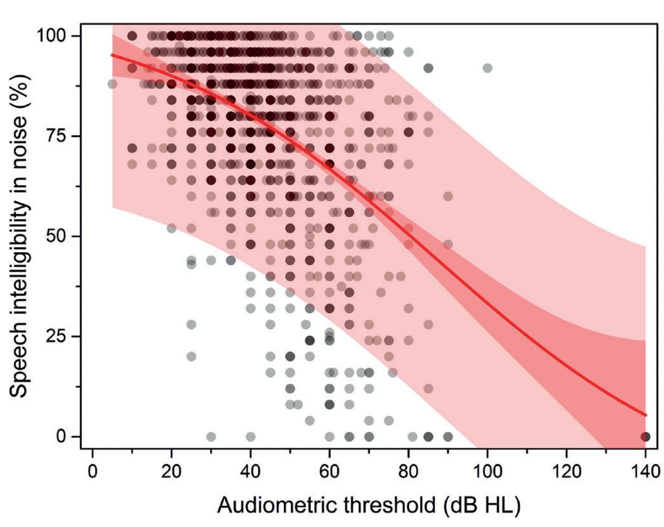

Figure 2. Prediction curve of the SiN intelligibility according to the auditory threshold.

It was identified that after 70 years of age, the performance in SiN hearing significantly decreased, being 10% lower in subjects between 70 and 79 years (p<0.05) and 18% lower in subjects over 80 years of age (p<0.05). In addition, a statistically significant decrease in the performance in SiN hearing was observed even from slight hearing loss (3.5% lower, p<0.001), although clinically this decrease will be hardly noticeable. The decrease was greater in moderate hearing loss (13.9% lower, p<0.001), severe hearing loss (25.2% lower, p<0.001), and profound hearing loss (54.2% lower, p<0.001).

It can be seen from the data in Figure 2 that the pattern of performance in SiN hearing describes a sigmoidal curve according to the auditory threshold. As can be seen in this prediction curve, there were individuals with especially high SiN intelligibility despite having a low auditory threshold (subjects that remain above the predicted intervals), and also individuals with especially low SiN intelligibility despite having a high auditory threshold (subjects that fall below the predicted intervals). These subjects were identified, and their characteristics were compared with those of the subjects that were within the predicted intervals.

It could be established that subjects with a high SiN intelligibility had a frequency of asymmetric hearing loss 69% higher than the subjects within the predicted interval (100% vs. 31%, p<0.001), while no differences were identified in age (p=0.052) or in sex (p=0.329). In the case of subjects with low SiN intelligibility, a higher age was identified as a statistically significant factor (78 vs. 69 years, p<0.001), while no differences were found in sex (p=0.530) or in frequency of asymmetric hearing loss (p=0.192).

DISCUSSION

It has been described that hearing-impaired subjects are highly noise-intolerant [10], and require a higher signal-to-noise ratio to understand speech [11]. Although a clear relationship between hearing loss and recognition of signals in noise has been reported in the literature, no study has been able to establish an accurate model that allows predicting speech intelligibility in noise based solely on the degree of hearing loss [4, 5], since there are many other factors influencing it. Figure 2 reveals that there is a reduction in SiN intelligibility close to 0.7% for every 1 dB of decrease in the audiometric threshold; however, the broad range of the prediction band is striking. A range in the prediction band of 75% makes it impossible to predict speech intelligibility in noise from only the audiometric threshold.

According to this very wide range in the prediction band, a very poor R^2 was obtained for the ability to predict SiN hearing from the hearing threshold (R^2=0.232). Therefore, although the auditory threshold clearly influences the performance in SiN hearing, other factors are expected to influence it.

Prior studies have noted the influence of aging on performance decline in tasks involving auditory processing skills, such as speech intelligibility in noise [12-14]. A reduction in auditory processing skills has been described in older adults [13, 15-19], but it has also been described as early as in middle-aged adults [20]. Slowing of neural processing and decreased neural inhibition resulting from aging likely interfere with auditory temporal processing [17]. It has been postulated that when listening becomes difficult due to either noise or age-related deterioration in the auditory system, a reallocation of resources occurs to support auditory processing. Unavailable resources can adversely affect processes such as the storage and retrieval functions of working memory, which affects the processing of auditory information [21]. However, a similar poor R^2 was determined for the ability to predict SiN hearing from age (R^2=0.279). Again, although age clearly influences the performance in SiN hearing, other factors are expected to influence it.

Another factor involved in a decrease in SiN intelligibility in subjects with hearing loss is the distortion effect as a consequence of recruitment, already described by Plomp et al. [22, 23] and Moore et al. [24]. Recruitment could explain the sky-slope pattern observed in SiN intelligibility from approximately 40 dB HL and above, as seen in Figure 2.

While it is believed that men have worse auditory performances than women, our data identify that the differences are not explained by sex, but by hearing impairment and age. This absence of differences due to sex has also been observed in the UK Biobank data, which shows a close similarity between the Digit Triplets Test (a test measuring SiN intelligibility) between men and women [25].

Our data have shown that the presence of an ear with a better hearing threshold significantly improves the SiN hearing in the contralateral ear in subjects with asymmetric hearing loss. As subjects with unexpectedly high levels of SiN intelligibility (subjects above the prediction curve in Figure 2) also had very high levels of asymmetric hearing loss, in the absence of an effect associated with age or sex. This preservation of SiN hearing in subjects who retain a better hearing ear could be explained since the signals from both ears are not processed independently, but are connected to each other in the brainstem [26], making it available for both auditory cortices.

Although intelligibility of signals under acoustically difficult conditions (as in noise) in reverberant environments or with competing signals is greatly improved with the presence of a second functioning ear, as a result of the head shadow effect, the squelch effect, and the binaural (or diotic) summation effect [27], none of them can explain the high intelligibility in the worst ear, since the words were presented only in one ear using contralateral masking. Most of the noise reduction ability of the human auditory system is highly dependent on access to time, level, and spectral differences perceived by each ear [28]. However, in the absence of information provided by the best ear, only central processes can explain this high SiN intelligibility.

Using monosyllables and not sentences is a limitation to the sensitivity of our methodology, since there are already matrices of sentences available in multiple languages, including Spanish [29]. White noise was used because the test selected in this study has been validated with this type of noise, although other forms of noise (as speech shaped or babble noise) can add even more sensitivity to the test.

This study has identified that although age and auditory threshold both clearly influence SiN hearing, neither of them is able to explain the wide range of observed performance. Certainly, other factors, such as a poor working memory [30] or deterioration in cognitive ability [31, 32], are involved in SiN hearing performance. Not including these cognitive factors suppose a limitation in this study, since they could explain the poor results of some subjects, whereas our study could only identify age as the only factor that explained results below the prediction curve. This finding, together with the observation that SiN intelligibility worsens even from slight hearing loss, may be arguments in favor of the early use of hearing aids in cases of hearing loss.

CONCLUSION

The results of this research have shown that preserving an ear with a better auditory threshold significantly improves performance in SiN intelligibility. This finding has not been previously described. Future studies should focus on confirming this protective effect of preserving a good auditory threshold in the contralateral ear.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of Instituto de Investigación Sanitaria La Fe, reference number FPNT-CEIB-04A.

Informed Consent: Written informed consent was obtained from the subjects who participated in this study.

Peer-review: Externally peer-reviewed.

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Conflict of Interest: The authors have no conflict of interest to declare.

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