Original Article

The Effect of Monaurally Fitted Hearing Aid Use on the Evolution of Presbycusis

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Abstract

Objective: The effect of hearing aid use on the evolution of presbycusis has not been well described in the literature, with only a handful of publications addressing this topic. This paper aims to evaluate the long-term use of amplification and its effect on pure-tone thresholds and word recognition scores.

Method: Monaurally fitted patients were followed with serial audiograms. Data was collected from hearing aid centers. Seventy-seven patients with presbycusis met the inclusion criteria and participated in the present study. The progression of hearing loss in both pure tone thresholds and word recognition scores were compared between the hearing aid ears (HA), and the non-hearing aid ears (NHA). Pure tone thresholds were analyzed by comparing the pure tone average at the initial and last audiograms. Word Recognition Scores (WRS) were analyzed using the model of Thornton and Raffin (1978), and by comparing the change in the absolute values of WRS from the initial to the last audiogram between the HA ear and the NHA ear.

Results: No significant difference in pure-tone thresholds between the HA ear and NHA ear was found at the last audiogram ($P = .696$), even after dividing the patients into groups based on the duration of amplification. Both methods of analysis of patients' WRS showed a statistically significant worsening in NHA ($P < .05$).

Conclusion: The present study supports the previously defined auditory deprivation effect on non-fitted ears, which showed worsening of word recognition over time and no effect on pure tone average. It provides an additional argument for the counseling of patients with presbycusis considering amplification, and highlights the importance of bilateral amplification in preserving the residual hearing of hearing impaired patients.

Keywords

presbycusis, auditory deprivation effect, monaural hearing aid, word recognition score

Introduction

Presbycusis is one of the most common causes of hearing loss in the adult population worldwide. According to the World Health Organization (WHO), by 2025 there will be approximately 1.1 billion people in the world over the age of 60 suffering from presbycusis, and one can expect the prevalence to increase as the population continues to age.[1] Aging has been shown to be the main risk factor for hearing loss in older individuals, with the risk of hearing-loss incidence tripling every 10 years after the age of 60.[2] The clinical course of presbycusis can vary between patients due to other related factors such as genetic variations, occupational exposure, and life style differences. However, presbycusis is considered among the most common disorders affecting older population and significantly reduces their quality of life on daily basis.[3]

Wearable hearing aids have been the mainstay of management for most cases of presbycusis globally.[4] Luckily, the amplification technology is rapidly improving and many hearing aid options are available nowadays to accommodate the needs of most patients around the world.[5] Unfortunately, many patients still do not receive proper amplification or receive only unilateral instead of binaural hearing aid fitting for their bilateral hearing loss. This problem usually happens due to high cost of hearing aids, lack of awareness, poor patient counseling, negative experience from using old hearing aids, lack of understanding of the negative impact of skipping amplification, etc.[6] A recent

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Cochrane review comparing the preference of using binaural versus monaural hearing aids showed that 39% to 77% preferred a binaural fitting.[7] However, many patients with bilateral presbycusis -or any bilateral sensorineural hearing loss- receive monaural hearing aid fitting.

Many researchers and clinicians have focused on the morbidity and the detrimental effect that presbycusis has on patients (eg, depression, decreased quality of life, and isolation),[8] and on the significant improvement in quality of life post hearing aid fitting.[9] However, only few studies addressed the long-term effects of amplification on the progression of hearing loss, most probably because of the difficulty of conducting this kind of longitudinal studies. Therefore, most of the studies in the literature investigate the effects of amplification over shorter periods of time (ie, weeks to months). For example, Gatehouse[10] investigated the short term improvement defined through the theory of perceptual acclimatization, and reported that speech identification ability improved significantly in the aided ear compared to the unaided ear over a time course of 6 to 12 weeks.

Silman et al[11] introduced the concept of auditory deprivation, where long term inadequate stimulation of an impaired ear resulted in significant decrease of word recognition scores (WRS) after 4 to 5 years, despite the fact that pure tone thresholds did not significantly shift. This has been described by few other studies.[12,13] Gelfand and Silman[14] and Hattori[15] even described this finding in children with sensorineural hearing loss. However, Song et al[16] did not find this kind of deterioration in WRS for patients who had used hearing aids for only 5 months. Hurley[13] had a follow up on their patients over 5 year period and reported progressive depression in the WRS in the unaided ear. However, their study did not examine patients over longer period of hearing loss and hearing aid usage (eg, 10-15 years). Auditory deterioration might change gradually and slowly or might change at different rates over longer periods of time according to the underlying pathophysiology.[17] Interestingly, Silverman and Silman,[18] Gelfand,[19] and Boothroyd[20] suggested a possible recovery from the auditory deprivation effect after switch from monaural to binaural hearing aid fitting after few years of follow up in some cases.

Because of the limited evidence presented in the literature regarding the changes in WRS and hearing thresholds induced by neural deprivation over longer periods of time, the present study aims to evaluate the change in WRS and hearing thresholds over different periods of time between the aided ear and the unaided ear.

Methods

Participants

Two hundred fifteen patient profiles were reviewed and collected retrospectively from 3 major hearing aid providers across Lebanon. Patients were excluded from the study if they were under the age of 45 years at the initial audiogram session, or if they had asymmetrical hearing loss defined by difference of 10 Decibel (dB) over 3 frequencies or by 15 dB at 1 frequency between patient's ears, or if they had an air-bone gap of more than 10 dB over 3 frequencies. Patients were also excluded if they are currently diagnosed or had a history of otological diseases (Meniere's disease, congenital hearing loss, or history of previous ear surgery).

Seventy-seven patient profiles met the inclusion criteria of the study. Forty-two patients (54.5%) were males and 35 (45.5%) were females, with the mean age of (68.19 ± 10.37 years) ranging from 45 to 94 years at the initial audiogram session. Because all participants had symmetrical hearing loss at the initial audiogram, the hearing aid side was decided based on the patient's preference. Forty-three of these patients (55.8%) used their hearing aid in the right ear.

Sixty-four patient profiles (out of the 77 selected profiles for the study) met the inclusion criteria of the study for examining the changes in WRS over time. The rest of the patients had no WRS taken at the time of follow up and were excluded from the analysis. Thirty-eight patients (59.4%) were males, and 26 patients (40.6%) were females, with the mean age of (67.29 ± 10.2 years) ranging from 45 to 94 years at the initial audiogram session. Thirty-six of these patients (56.3%) used their hearing aid in the right ear.

All patients were diagnosed with presbycusis and were fitted monaurally immediately post diagnosis, but the exact duration of hearing loss post onset and prior to hearing aid fitting might vary according to patients' claims at the time of hearing evaluation. However, all patients denied feeling the hearing loss for more than 2 years prior to the initial hearing evaluation. All patients consistently used their monaural hearing aids for at least 3 years. All patients received a clear explanation about the importance of binaural amplification at the time of their initial hearing aid fitting. All patients were monaurally fitted according to their preference regarding technology and cost.

The present study is approved by the institutional review board at the primary author's university. Informed consent was not collected since this is a retrospective trial in agreement with the institutional review board.

Procedures

The audiological evaluation consisted of routine otoscopic examination, tympanometry, air conduction, and bone conduction pure tone thresholds for the octave frequency range of (250-8000 Hz), and WRS performed in an unaided manner at all clinical sites and at each visit using the word lists from the Arabic speech auditory test.[21]

Each audiology center required from the patient a regular follow-up every 2 to 3 years to repeat the audiological

evaluation and adjust the hearing aid fitting. Patients were organized into 4 groups according to the duration of using their monaural hearing aid: 3 to 5, 5 to 10, 10 to 15, and >15 years. Most of the 77 patients had serial audiograms over the years that fit the criteria of more than 1 duration group, thus the appropriate data from these patients were used in more than 1 group to demonstrate the progression over time (Table 1). The initial audiogram and the last audiogram for every patient in each group was extracted. The hearing thresholds and the unaided WRS from each audiogram were analyzed for the aided ear (HA ear) and for the unaided ear (NHA ear). Then, the hearing thresholds and WRS of the HA ear were compared to the hearing thresholds and WRS of the NHA ear.

Pure tone thresholds were analyzed by comparing the pure tone average of 500, 1000, 2000, 4000, and 8000 Hz and by comparing the single frequencies, at the initial and last audiograms between HA ear and NHA ear. WRSs were analyzed using the table of confidence model of Thornton and Raffin.[22] This model (Table 2) compares 2-word recognition scores and defines if the difference is significant between them. In our model we took each ear separately and compared the pre-fitting to the post-fitting results after treatment. If the 25-word score post-fitting result was less than the lower limit projected from the pre-fitting result, then the current ear had a significant change. For example, if the pre-fitting word recognition score result was 96% and the patient has 70% WRS on the post treatment result which is less than the result projected by the Thornton and Raffin method (86%-100%) then this result is statistically different. The collected results (either significant or not significant) were tabulated and were analyzed using a Mc Nemar test of significance. The WRSs were also analyzed by comparing the change in the absolute values of WRS from the initial to the last audiogram between the HA ear and the NHA ear. A paired sample *t*-test was used to analyze the hearing thresholds and WRS data. A two-tailed *P*-value of <.05 was set for statistical significance, and statistical analysis was performed using SPSS version 23 (IBM Inc., Somers, NY, USA).

Results

Out of the 215 patient profiles that were collected for the present study; 37 were excluded because these patients were younger than 45 years at the time of the initial audiogram session, and 101 were excluded because these patients had air-bone gap larger than 10 dB at 3 different frequencies, or did not meet the other inclusion criteria of the present study. The data from the 77 patients who met the inclusion criteria were analyzed.

When comparing the change in hearing thresholds between the initial and the last audiogram for all duration groups combined, all tested frequencies showed significant increase in the hearing threshold ($P < .001$). However, no significant difference between the HA ear and NHA ear was found at the last audiogram session ($P = .696$) (Figure 1). The hearing thresholds at initial and last audiogram sessions for the 4 groups were analyzed (Figure 2). Again, no significant difference was found in the change of pure tone thresholds between the HA and NHA ears ($P > .115$).

Table 1. Distribution of Patients According to Their Serial Follow Up Time of Visits.

Duration of hearing aid usage in years	Number of patients who presented for follow up (%)
3-5	27 (35)
5-10	48 (62.3)
10-15	20 (26)
15-20	5 (6.5)

Patients' WRSs were first compared using the Thornton and Raffin method (Table 2). According to this method, there were 10 patients who had a significant worsening in the NHA ear compared to no significant change in the HA ear. None of the patients showed a significant deterioration in the HA ear with a simultaneous non-significant change in the NHA ear (Table 3). Using the McNemar test, this analysis showed a statistically significant difference in favor of the HA ear ($P = .002$).

Another test was performed using a paired *t*-test for the WRS percentage difference between first and last audiogram sessions comparing HA and NHA ears. NHA ear showed a mean deterioration of $7.32\% \pm 3.3\%$ more than the HA ears ($P = .03$) (Figure 1). This analysis also revealed a significant effect of lack of amplification on worsening the WRS due to neural deprivation over time.

Discussion

Previous studies have demonstrated that patients with presbycusis have a significant improvement in quality of life when using hearing aids.[9,23] However, many patients with bilateral presbycusis -or any bilateral sensorineural hearing loss- receive monaural hearing aid fitting, due to several reasons discussed above (eg, financial, lack of awareness, poor patient counseling, negative previous experience, etc.). Although the disease progression of presbycusis is well documented including a variable slow decline in both pure tone averages and WRS, the effect of hearing aid usage on the progression of hearing loss has not been adequately explored in the literature so far. Therefore, the importance of studying the effect of abstaining amplification in one ear on the hearing thresholds and WRS is critical to highlight the importance of binaural hearing aid fitting for these patients, and to avoid any harmful consequences of pursuing monaural fitting for bilateral hearing loss.

Table 2. Thornton and Raffin Model for Significant Change.

Prefitting test	Post treatment test	Prefitting test	Post treatment test
Word recognition score %	Word recognition score %	Word recognition score %	Word recognition score %
0	0-4	52	34-70
2	0-10	54	36-72
4	0-14	56	38-74
6	2-18	58	40-76
8	2-22	60	42-78
10	2-24	62	44-78
12	4-26	64	46-80
14	4-26	66	48-82
16	6-32	68	50-84
18	6-34	70	52-86
20	8-36	72	54-86
22	8-40	74	56-88
24	10-42	76	58-90
26	12-44	78	60-92
28	14-46	80	64-92
30	14-48	82	66-94
32	16-50	84	68-94
34	18-52	86	70-96
36	20-54	88	74-96
38	22-56	90	76-98
40	22-58	92	78-98
42	24-60	94	82-98
44	26-62	96	86-100
46	28-64	98	90-100
48	30-66	100	96-100
50	32-68		

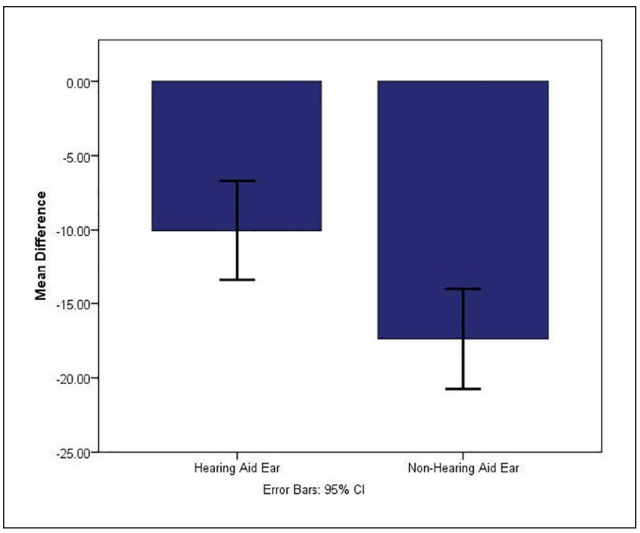

Figure 1. Mean decrease in percentage of word recognition score between hearing aid fitted and non-hearing aid fitted ear.

All patients had a significant worsening of hearing threshold over time when comparing the initial and the last audiograms ($P < .001$). However, no significant difference between the HA ear and NHA ear was found at the last audiogram session ($P = .696$) (Figure 2). The data from each of the 4 duration groups also showed no significant difference in pure tone threshold changes between HA and NHA ears ($P = .115$) (Figure 3). The worsening in pure tone thresholds seen in both ears is due to the natural process of presbycusis.

Silman et al[11,24] proposed that auditory deprivation manifests in significantly worsening WRS in the unaided ear when compared to its contralateral counterpart, a finding supported by few other authors.[12,13] However, Song et al. examined this assumption over a shorter period of time (ie, 5 months), and their study showed no significant change in WRS in HA ear compared to NHA ear. These previous studies suggest that the natural progression of presbycusis is indeed variable, but typically seen over several years and

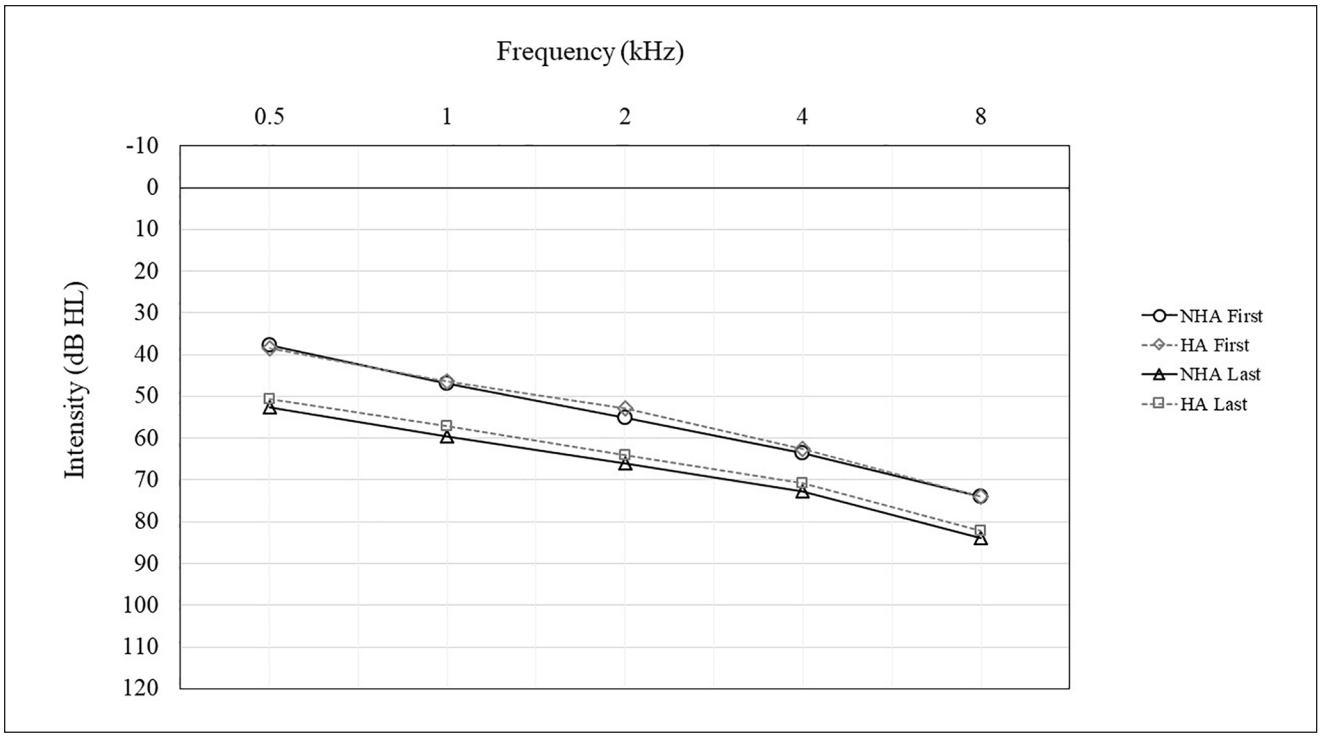

Figure 2. Comparison audiogram of hearing aid group versus non-hearing aid group at first presentation and most recent visit.

Table 3. Word Recognition Score Significant Change Pre-Fitting and on Follow Up between Fitted and Non-Fitted Ears.

	Hearing aid ear	
	Significant change	Nonsignificant change
Non-hearing aid ear		
Significant change	45	10
Nonsignificant change	0	9

$P = .002$.

longer periods of time. The present study explored the change in WRS between the HA ear and the NHA ear over different periods of time (ie, 3 to >15 years), by comparing initial to last WRS. The findings showed significant deterioration of the WRS in the NHA ear compared to the WRS in the HA ear ($P = .002$). Due to the limited number of patient profiles that met the inclusion criteria for the WRS analysis in the present study, there was not enough sample size to analyze the WRS changes within the individual duration groups.

The differential effect of amplification on word recognition score, as opposed to pure tone threshold can potentially be explained by a detailed exploration of the anatomo-physiological studies investigating the changes in the auditory system that result from peripheral hearing loss. Indeed, it is well known that cochlear hearing loss due to hair cell degeneration results in a progressive loss of the dendritic processes inside the cochlea, followed by loss of the cell bodies of the spiral ganglion cells. This loss is proportional to the duration of deafness.[25]

Speech recognition requires more complex neural and central coding processing as compared to pure tone detection at threshold level. Therefore, high demand on the neural coding is required in this case. The frequency[26] and intensity[27] coding in the auditory nerve depend on the number of stimulated neurons and the firing rate in each neuron. Neural degeneration affects both these mechanisms causing a reduction in the number of functional neurons and abnormal firing rates in the affected neurons. This degenerative process affects the frequency and the temporal resolutions as well as the formant structure perception of the auditory signal. This results in a more limited speech recognition ability of the patient and causes a reduction in the word recognition score (WRS) over longer periods of time as demonstrated by the

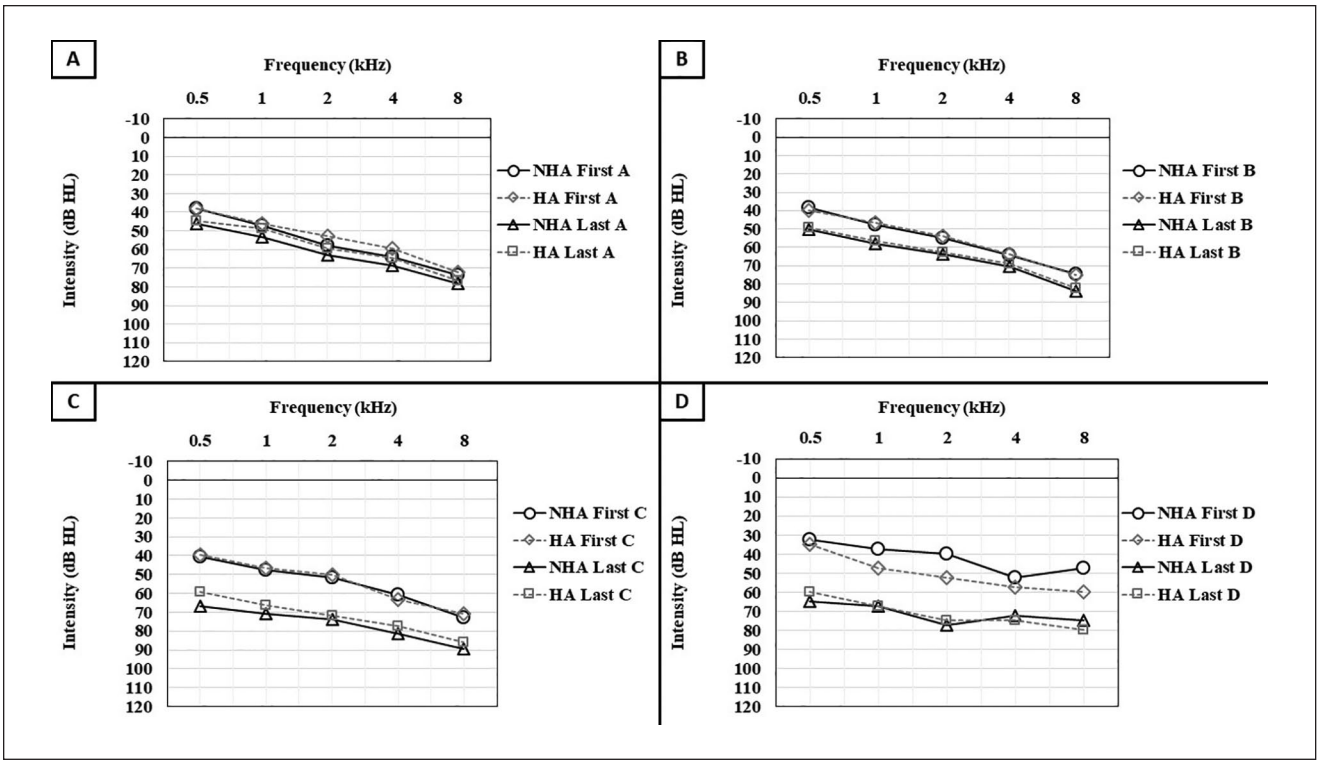

Figure 3. Comparison audiogram of hearing aid group versus non-hearing aid group at first presentation and (A) 3 to 5 years. (B) 5 to 10 years. (C) 10 to 15 years. (D) >15 years.

changes in the WRS of the present study. However, one should keep in mind that the effect of abstaining amplification on pure tone thresholds probably would be detected over a longer observation period than the periods examined in the present study.

In studies of deafened animals, chronic electrical stimulation of the cochlea with cochlear implantation helps reduce the above mentioned degeneration of spiral ganglion cells.[25] While no studies have been conducted on lesser degrees of hearing loss, we suggest that a similar mechanism might be at play in this series, where acoustic stimulation of the cochlea provides neurotrophic support that can preserve the anatomy and function of the higher auditory pathway.

Moreover, advanced central auditory processing mechanisms involved in word recognition are complex and include several aspects such as temporal analysis, pitch analysis, phonemic analysis, pattern recognition, neural-template identification, auditory memory, paralinguistic analysis, etc. These advanced central auditory processing mechanisms require accurate and detailed input from the peripheral auditory system. Lack of adequate stimulation and the progressive deterioration in the accuracy of the neural coding from the peripheral auditory system limits the development and maintenance of neural synapsis in the central regions responsible for different aspects of the auditory processing. The complexity of central processing involved in identifying the presence or absence of pure tone sounds at threshold levels is minimal compared to the complexity of central processing required for word recognition at suprathreshold levels. The findings of the present study showed that the deterioration in the hearing thresholds happened bilaterally with no significant difference in hearing thresholds between the aided and unaided ears in all groups. The findings also showed that WRS was significantly deteriorated in the unaided ear compared to the aided ear and the difference increased with longer duration of using the unilateral hearing aid. These findings suggest that the degenerative effect on hearing threshold is mainly due to peripheral deterioration that could be independent from the use of amplification, while the degenerative effect on word recognition scores is mainly due to retrocochlear and central deterioration caused by lack of proper stimulation and input coding.

Silverman and Silman[18] and Boothroyd[20] reported that this effect is potentially reversible in some cases over time, by fitting the previously unaided ear. However, the course of improvement was not detailed in their study. The WRS re-improvement by fitting the NHA ear was not examined in the present study, but we highly recommend the exploration of this issue in future research due to its importance in the management of presbycusis.

Conclusion

In conclusion, the use of amplification has a significant impact on preserving the auditory function in patients suffering from sensorineural hearing loss (ie, presbycusis). This was demonstrated by the significant difference in WRS between NHA ear and HA ear. The results of the hearing thresholds did not show the same effect as in WRS. This highlights the importance of not relying on the pure tone thresholds only to quantify the neural degeneration and the progression of hearing loss in general and in the NHA ear in particular. The findings of the present study also highlight the importance of binaural hearing aid fitting for patients with sensorineural hearing loss. Therefore, patient awareness, counseling, and cost efficiency should be improved when fitting patients with hearing aids.

Declaration of Conflicting Interests

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