Speech Perception and Information-Carrying Capacity for Hearing Aid Users of Different Ages

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Key Words

Aging · Speech perception · Hearing aid use · Monosyllabic score

Abstract

Hearing impairment in the elderly is usually treated with conventional hearing aids; however, a large number of older people do not achieve sufficient speech recognition with hearing aids. The aim of the study was to describe speech perception with hearing aids in comparison to pure-tone hearing loss and maximum speech recognition scores for phonemically balanced words. Data from 392 hearing aid users with different degrees of hearing loss were evaluated retrospectively. In particular, pure-tone thresholds, the maximum monosyllabic word score, and the monosyllabic word score in quiet at conversational level with a hearing aid were analysed. The results showed that speech perception scores decline with increasing age. Even when corrected for pure-tone hearing loss, a significant decline in speech recognition scores after the age of 80 years was observed. Regarding the maximum monosyllabic word score, the effect is smaller but still observable; thus, speech recognition with hearing aids is significantly lower for older subjects. This can be attributed partially to the reduction of the information-carrying capacity in this group.

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Published by S. Karger AG, Basel

Introduction

Deterioration in hearing ability that occurs with aging is a complex process that can vary in severity from minor to substantial. According to van Rooij et al. [1990], the proportion of elderly persons with problems in perceiving speech doubles per decade of life from 16% at the age of 60 to 32% at the age of 70 and to 64% at the age of 80. According to the ISO report for thresholds of hearing loss versus age, every second person above 65 years of age needs hearing aid (HA) amplification. Left untreated, presbycusis of a moderate or greater degree affects communication and reduces quality of life substantially. Where HAs no longer provide benefit, cochlear implantation is the treatment of choice with excellent results even in elderly subjects [Hast et al., 2015].

Most severely hearing-impaired adults have a history of some HA use where they have experienced steadily diminishing speech perception ability. As the main goal of cochlear implantation is the improvement of speech understanding, beyond what is feasible by conventional amplification, a thorough HA evaluation is advisable prior to cochlear implant (CI) surgery. One important outcome measure in HA evaluations is the perception of monosyllabic words at a conversational level. An individual's speech recognition score with HAs at conversational level [SRS₆₅(HA)] varies dramatically with pure-tone hearing

Fig. 1. **a** Speech recognition score for Freiburg monosyllabic words as a function of pure-tone loss measured as pure-tone average for thresholds at 0.5, 1, 2, and 4 kHz (4FPTA). The solid line represents PB_{max} , and the dotted line represents scores at 65 dB with HAs [$SRS_{65}(HA)$]. **b** Difference of the functions shown above [$PB_{max} - SRS_{65}(HA)$].

loss. However, the average dependency between the two variables can be characterized by a logistic function [Hoppe et al., 2014, 2015] with an anticipated 100% at mild hearing losses and nearly zero for profound hearing loss. This function is shown in figure 1a. In a prior study [Hoppe et al., 2014], a similar function was found for the maximum phonemically balanced word score (PB_{max}) measured under headphones (fig. 1a, dotted line).

The PB_{max} defines the maximum monosyllabic word recognition score for phonemically balanced words [Gelfand, 1997]. According to Halpin and Rauch [2008], the PB_{max} can be used as an estimator for the information-carrying capacity (ICC) of the auditory system. Within the process of HA evaluation, the PB_{max} characterizes the potential for the best possible speech recognition with HAs at a conversational level of 65 dB sound pressure level (SPL). As shown in figure 1, not all HA users can transfer their full ICC into speech recognition scores using conventional amplification, and a gap of up to 30% remains. Figure 1b shows that this gap depends on the amount of pure-tone hearing loss with a maximum reached for severe hearing loss levels. For severe hearing losses, the potential HA performance is limited by an insufficient residual dynamic range [Zwartenkot et al., 2014] and the aversiveness to the high levels of acoustic amplification [Hoppe et al., 2014]. Additionally, the effect of aging on cognitive processes is a major contributing factor affecting HA performance [Walden and Walden, 2004; Müller et al., 2016].

The aim of our retrospective analysis was a detailed investigation of the age dependency of the ICC. Another question was whether the perceptual gap between PB_{max} and $SRS_{65}(HA)$ depends on the subject's age.

Methods

In total, HA evaluations of 392 subjects with bilateral sensorineural hearing loss performed in the Audiological Centres of Erlangen ($n = 156$) and Berlin ($n = 236$) were analysed retrospectively. The data from 784 ears were analysed separately. The mean age of the subjects was 65 ± 16 years and ranged from 18 to 96 years.

The data were collected as part of clinical routine for HA performance assessment. All subjects had been supplied with HAs and had at least 3 months of experience using them. Approximately 50% of the subjects were first-time users. All had completed the HA selection and fitting process at least 3 months before the visit. Prior to aided hearing assessment, the HAs were technically checked. All patients attended a follow-up visit with their HA professional before the evaluation visit. Only native German-speaking subjects with no known mental disabilities influencing audiometric test results were included in the analyses. Subjects with air-bone gaps of more than 5 dB were excluded from the analyses.

Each ear was tested separately. The pure-tone average threshold for the frequencies 0.5, 1, 2 and 4 kHz was calculated for each ear. Speech audiometry using Freiburg monosyllabic words was measured via headphones in the unaided condition for each ear. The speech stimuli were presented at 65 dB SPL initially, and the corresponding speech recognition score, i.e. correct word score in percent, was recorded. The presentation level was increased stepwise by 10–15 dB until a maximum score of 100% was achieved or

Fig. 2. Scatter representation of the maximum monosyllabic score ($PB_{\max}$) as a function of 4-frequency average at 0.5, 1, 2, and 4 kHz (4FPTA). Each dot represents the result from one ear.

the maximum score achievable ($PB_{\max}$) that was below the patient's uncomfortable loudness level. For all calculations, the MathWorks™ Matlab® software was used.

Results

Figure 2 shows a scatter plot of the $PB_{\max}$ scores for all 784 ears as a function of the average pure-tone loss. While there is a strong tendency for lower $PB_{\max}$ with increasing 4-frequency pure-tone average, there is large variability in the data. For severe hearing loss between 70 and 80 dB, for example, $PB_{\max}$ varies between 0 and 100% but the data also reveal that subjects with a $PB_{\max}$ of 40% may have a hearing loss ranging from 50 to 118 dB HL.

The difference value between the average $PB_{\max}$ performance function and each individual $PB_{\max}$ was calculated (i.e. curve A in fig. 1a). This adjustment allows for an investigation of hearing loss independently of other influencing factors. Figure 3 shows the results of the adjusted $PB_{\max}$ versus the subjects' age. For transparency, data were summarized in groups of one decade and shown as box plots to illustrate the data distribution. Median values are shown as a horizontal line within each box, limited by the upper and lower quartile. Lower and upper whisker plots represent 5 and 95% percentiles, respectively. The dashed line denotes the zero line indicating 'average' performance.

With increasing age for each subgroup, a tendency for larger discrepancies from the average performance is observed. For those below 70 years of age, no systematic deviation from the average performance line can be found. Above 70 years of age, a clear trend for decreasing performance is present. Discrepancies to the average performance increase from -3% (70–80 years) to -7% (80–90 years) and -18% (>90 years). Additionally, the variability within each age group increases with increasing age: interquartile ranges vary from 15–17% for younger groups to 26% for the group aged 80–90 years.

Discussion

Successful decoding of speech signals requires functional integrity at all stages along the auditory pathway including the inner ear, cochlear nerve, brainstem, and ultimately the auditory cortex. From the functional point of view, not only is sensitivity important, but also sufficient temporal and spectral resolutions are required for speech recognition and comprehension.

This study investigated the deterioration of speech recognition in the elderly. While there is a great deal of knowledge about the loss of threshold sensitivity for pure tones with increasing age, little is known about the progressive decline of speech recognition in the elderly. The study shows that speech recognition is affected to a great-

Fig. 3. Difference between individual PB_{max} scores and average performance (A) as a function of age. Box plots summarize data of one decade from 40 to 90 years. Figures within the box plots represent the number of ears within the range.

er extent than would be predicted from the pure-tone thresholds, alone, for the older elderly group of >80 years of age. In particular, the PB_{max} , a measure of the ICC, is significantly reduced in this group compared to the younger elderly group.

Recent reports have demonstrated that aided speech perception for older HA users is significantly lower than for younger adults [Hoppe et al., 2014; Müller et al., 2016]. Though HA fittings were technically verified, older HA listeners ≥ 70 years achieved speech recognition scores that were 10–20% lower than for younger HA listeners. The primary hypothesis was that the HA users in the more senior groups do not receive the appropriate amplification and sound quality from their HAs. Our study, however, shows that even when presenting amplified speech stimuli via headphones, the speech recognition score is significantly reduced in the older elderly group compared to the younger elderly groups. This reduced ICC for older listeners is supported by models of degeneration of the central auditory pathway that indicate that feature extraction and pattern recognition for auditory patterns such as speech are reduced in the elderly [Humes, 1996]. Currently, the question remains open whether the reduced speech recognition depends on cognitive factors located in the cortex or on auditory signal processing dysfunction taking place at cochlear or brainstem levels.

On the other hand, a number of studies indicate that older subjects who are provided with a CI can achieve speech perception scores that are identical or very similar to younger CI users [Nakajima et al., 2000; Orabi et al., 2006; Clark et al., 2012; Hast et al., 2015]. Further, elderly CI listeners also demonstrate benefit from individually tailored auditory training therapy that can result in auditory outcomes marginally below those observed for younger CI users [Schumann et al., 2014].

The use of the PB_{max} as an estimator of the ICC was first proposed by Halpin and Rauch [2008]. They demonstrated that the PB_{max} is a more valid measure for an estimate of everyday speech recognition than the pure-tone threshold levels in subjects with sensorineural hearing loss. As shown in figure 2, identical averaged pure-tone hearing losses result in a very different ICC. Obviously, the 4-frequency pure-tone average is a rough measure only for overall hearing ability and considers neither influencing temporal aspects nor the frequency characteristics of a hearing loss; therefore, the PB_{max} provides important additional information. However, when estimating speech perception in everyday life one has to consider that the PB_{max} is not achieved in many cases. As shown in figure 1, differences between PB_{max} and speech recognition scores with HA at 65 dB SPL can be as large as 30%. Considering the simple measurement of the PB_{max} , it provides an excellent tool when screening for CI candidacy

[Hoppe et al., 2015]. As an example, when a subject's PB_{max} is below 60% for amplified speech under headphones for monosyllabic words, it is feasible that their corresponding monosyllabic word score at conversational level via an HA will be 30% or lower. Such poor performance with conventional amplification would clearly make this individual a candidate for CI according to the commonly applied audiological criterion across CI clinics. Clinically, evaluation of the PB_{max} requires measurements by the standard audiometer and headphones only and is independent of the actual HA settings. As such the PB_{max} provides a simple and readily available method to all audiology centres for the identification of potential CI candidates amongst the hearing-impaired elderly population for further referral to and evaluation by specialist implant teams.

Conclusion

The PB_{max} provides a valid estimator for the ICC and hence also the maximum ability for speech recognition and understanding in everyday life. In contrast to pure-tone thresholds, it considers both temporal aspects and suprathreshold auditory processing involved in speech perception. Therefore, estimation of the ICC via measurement of the PB_{max} should be used routinely during the evaluation for CI candidacy for patients of any age.

Disclosure Statement

T. Hocke is an employee of Cochlear Deutschland GmbH & Co. KG. The other authors (U.H., A.M., A.H.) state that there is no conflict of interest to be disclosed.

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