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Research Article

Hearing Screening in Adults Over the Age of 60: Validation of an Appropriate Stimulus Level for Successful Hearing Screening

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Abstract

Introduction: The consequences of untreated hearing loss in adults can be severe, affecting both their quality of life and economic well-being. Hearing screening for adults may help prevent such impairments in life. The newborn hearing screening demonstrates the efficacy of systematic preventive hearing screening, with impressive success in the countries where it was implemented. The aim of this study was to determine if hearing screening based on auditory brainstem responses (ABR) for adults can be implemented.

Methods: 100 adults (age = 60 – 89 years) underwent ABR-based screening and pure-tone audiometry (PTA). Subjectively perceived hearing impairment was assessed using the Hearing Handicap Inventory for the Elderly Screening Version (HHIE-S) questionnaire.

Results: A screening level of 65 dB for ABR-based screening achieved the highest values for specificity (81.4%) and sensitivity (88.9%). Cases of hearing loss identified through screening were validated by corresponding PTA data (36% with significant hearing loss). The questionnaire identified subjectively perceived hearing impairment in 58% of the participants.

Conclusion: ABR-based hearing screening at 65 dB is a realistic and efficient method to identify adults with significant hearing loss and guide them towards hearing rehabilitation. The test should now be evaluated for suitability for daily use by general practitioners.

Keywords: Hearing screening, Age-related hearing loss, Auditory evoked potentials

Introduction

Hearing loss is a critical health risk factor that affects nearly 20% of the global population [1]. There is a wide range of causes of hearing loss and a wide range of individuals affected, spanning from newborns to elderly, with an estimated 65% of those aged over 60 years experiencing significant hearing loss. In older adults, this can have severe implications for overall health: Starting with decreased occupational performance followed by a negative impact on their economic potential, hearing loss may lead to social withdrawal [2], a severe reduction of quality of life, and even increased potential dementia progression [3-6]. Early measures for appropriate hearing rehabilitation can prevent further deprivation of auditory processing and, thus, significantly mitigate these

negative effects of hearing loss [7,8]. This, however, requires timely identification of affected individuals.
A positive example of the early detection and management of hearing loss is the newborn hearing screening (NHS), which has globally contributed to significant improvements in the hearing development of children with hearing loss. In Germany, for instance, most newborns are screened for potential hearing loss within the first week of life. In the case of a negative result, they undergo further diagnostic evaluation and, if necessary, hearing rehabilitation.
Automated auditory brainstem response (ABR) testing has proven particularly effective in such screenings, as it can be conducted reliably within a few minutes. Its simplified result classification into “pass” and “fail” provides a clear indication of whether further diagnostic steps are needed [9].
The increasingly evident risk of hearing loss in older adults has led to numerous initiatives to detect hearing loss as early as possible using simple methods [10-20]. Therefore, the present study aimed to investigate the feasibility of introducing hearing screening for older adults, specifically individuals over 60 years of age.
For this purpose, it is first required to determine an appropriate stimulus level for the screening, hereinafter referred to as “screening level”. Due to the physiological decline in hearing with age, the screening level needs to be considerably higher than the standard screening level of 35 dBHL used in newborns. The primary aim of this study was to determine the screening level at which the screening results show high specificity and sensitivity.

Methods

Inclusion criteria
Eligible participants were individuals > 60 years based on the definition of older adults by the United Nations, who were free of infections of the upper respiratory tract [21]. Pre-existing diseases and hearing loss were not considered to be exclusion criteria.

Ethics
This prospective study was approved by the local ethics committee of the university clinic of Wuerzburg (74/24) and conducted in accordance with the Declaration of Helsinki, and Parts I and II of ISO 14155 (2021) regarding the conduct of clinical investigations involving human subjects.

Measurement Methodology
The test procedure was divided into three segments.
First, the specialized Hearing Handicap Inventory for Elderly Screening questionnaire (HHIE- S) was used for subjective initial assessment of the participants’ hearing ability [18]. This questionnaire contains 10 questions about hearing ability, aiming to identify hearing problems in daily life. For example, it asks about conversations with family members and difficulties watching television or listening to the radio. Each “yes” response is awarded four points, which are then summarized to produce a total score. The higher the total score, the greater the handicap caused by the hearing loss. Scores can range from 0 (no handicap) to 40 (maximum handicap). Audiological evaluation is recommended for scores of 10 points or higher. The HHIE-S questionnaire was used in German.
Second, the hearing screening was performed. The device *easy Screen* (Maico, Berlin, Deutschland, figure 6) was used. This device has already been proven to be effective in NHS [9]. It allows for automated binaural ABR testing at a pre-set screening level. Auditory evoked potentials (AEP) are recorded simultaneously on both sides between the center of the apex and the mastoid. The integrated CE-Chirp is used as acoustic stimulus, delivered via in-ear headphones at a stimulus rate of approximately 90/s. The EEG is analyzed automatically during the test. Once an AEP is detected, the test is terminated with a “pass” result. If no AEP is detected within 3 minutes, the test concludes with the result “fail”, indicating further evaluation is necessary. The screening results are reported separately for the left and right ear. For this study, the devices’ manufacturer enabled the option to select various stimulus levels for the screening, ranging from 35 dBHL to 70 dBHL in 5 dB increments. This allowed the hearing thresholds of the participants to be determined with a precision of up to 5 dB using the screening device.

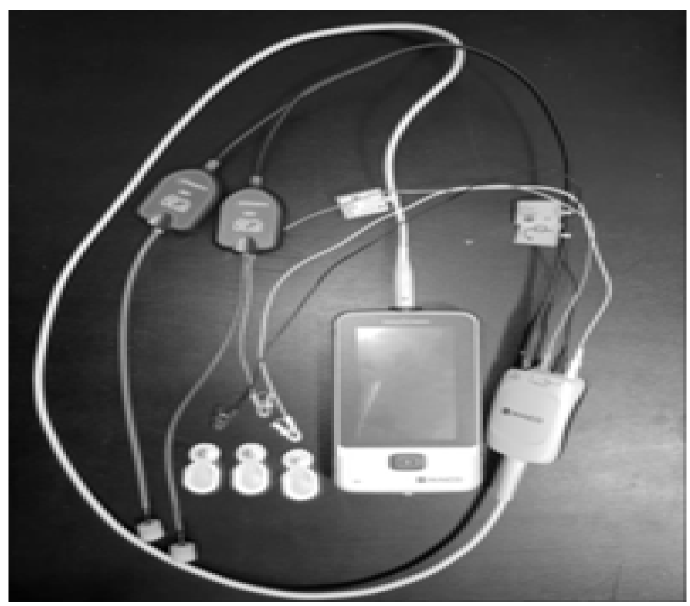

Figure6: Screening device EasyScreen® (MAICO diagnostics, Berlin)

Third, the participants’ PTA was determined to assess the subjective hearing threshold. Pure tones in the frequency range of 0.25 kHz to 8 kHz were presented via headphones (TDh39, Telephonics, USA) and bone conduction transducers (B71, RadioEar, USA) at varying sound levels until the hearing threshold was established through participant input. The obtained complete audiogram with air and bone conduction thresholds can be interpreted based on the curve's pattern. Physiological patterns, presbycusis, conductive hearing loss (e.g., middle ear effusion, otitis media), or noise-induced trauma (e.g., a C5 notch at 4 kHz) can be clearly identified.

In this study, two key values were determined: (1) specificity: the number of normally hearing participants falsely identified as having hearing loss during the screening, and (2) sensitivity: the number of participants with suspected treatment-requiring hearing loss correctly identified as having hearing loss during the screening. The calculation of specificity and sensitivity is primarily based on the PTA3 (Pure Tone Average at 1k, 2k, and 4 kHz) thresholds [22]. Participants who exceeded a predefined PTA3$_{Ref-}$ threshold or were already fitted with hearing aids were classified as individuals with abnormal hearing results. All other participants were considered normal-hearing (Rule 1). Another reference value concerned the screening hearing threshold (ScPG$_{Ref)}$. If participants did not pass this level during the screening, they were classified as individuals with abnormal hearing results; otherwise, they were considered normal-hearing (Rule 2). Specificity was then calculated by the number of participants classified as individuals with abnormal hearing screening results (Rule 2) divided by the number of normal-hearing participants based on PTA3 (Rule 1). Sensitivity was calculated by the number of participants classified as individuals with abnormal hearing screening results (Rule 2) divided by the number of individuals with abnormal PTA3 results (Rule 1).

Statistical Analysis

R for Windows 3.5.3 (R Core Team, USA) was used for statistical data analysis. Descriptive statistics were used to analyze age, hearing thresholds, and screening level data. Correlation analysis was conducted between PTA3 thresholds, the screening hearing thresholds, and the questionnaire results. The significance level was set at 5%.

Results

Study Participants

100 participants were included in the study. Participants were between 60 and 89 years old (mean 69.3 years). Figure 1 illustrates the age distribution of the participants.

Measurement outcomes

All participants completed the questionnaire; screening was successfully performed in all
participants; audiograms were obtained in all participants:

The correlation analysis between PTA3 thresholds and screening hearing thresholds showed a strong correlation of rp = 0.65 ($p < 0.01$).

The average hearing screening threshold was 52.5 dBHL. This threshold was far too low as a reference value (39% specificity) to achieve sensitivity of close to 100%. To determine the optimal screening level, various combinations of reference values for screening levels and PTA3 thresholds were analyzed. Table 1 presents the screening and PTA3 reference levels that were most promising in terms of specificity and sensitivity for reliable screening results. The optimum was achieved with a screening reference level (ScRef) of 65 dBHL and a PTA3 reference threshold (PTA3Ref) of 45 dBHL. This combination achieved a specificity of 81.4% and a sensitivity of 88.9%.

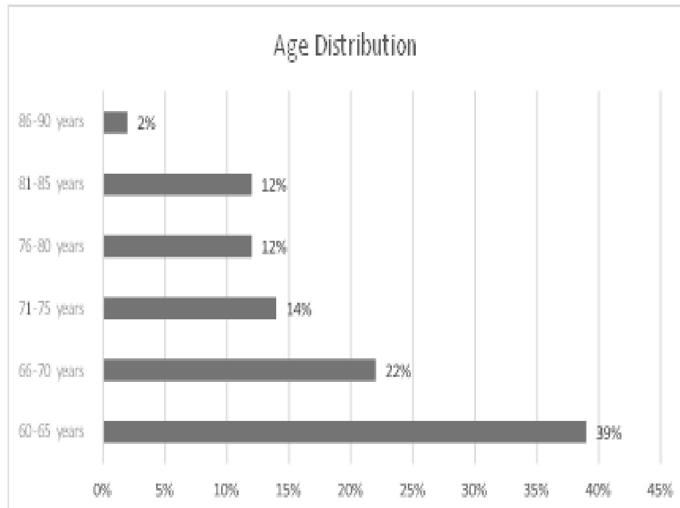

Figure1: Age distribution of the participants.

Screening level ScPG$_{Ref}$ [dBHL]	PTA3$_{Ref}$ [dBHL]	Specificity [%]	Sensitivity402 [%]
70	40	85.5	77.5[403]
65	40	80.0	80.0[404]
60	40	72.7	90.0[405]
55	40	60.0	95.0
70	45	86.4	86.1[406]
65	45	81.4	88.9[407]
60	45	69.5	91.7[408]
55	45	57.6	97.2
70	50	83.6	85.3[409]
65	50	78.7	88.2[410]
60	50	67.2	91.2[411]
55	50	55.7	97.1[412]

Table1: Specificity and sensitivity for different screening levels and PTA3 values.

Figure 2 shows the average audiograms of both groups normal-hearing (n = 59) and individuals with abnormal hearing results (n = 36) for an optimal combination of $ScPG_{Ref}$ and PTA3

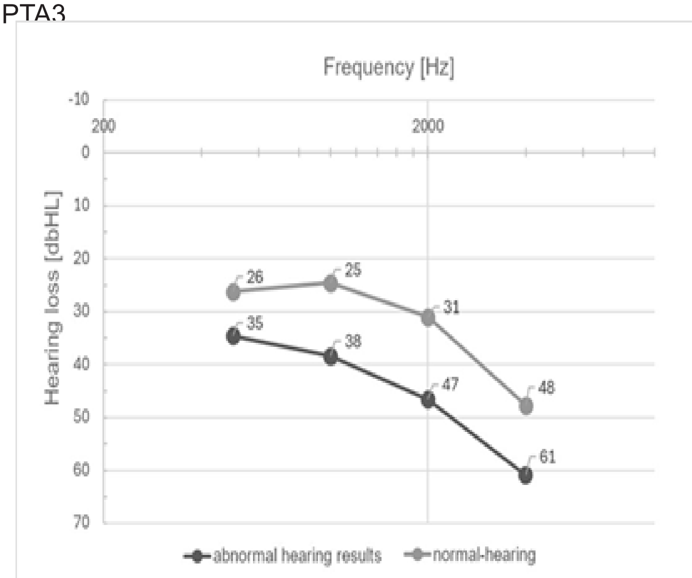

Figure2: Averaged audiograms of the groups individuals with abnormal hearing results and normal-hearing.

Correlation analysis showed a significant correlation between screening thresholds and PTA3 (rp = 0.65 ($p < 0.01$) (Figure 3).

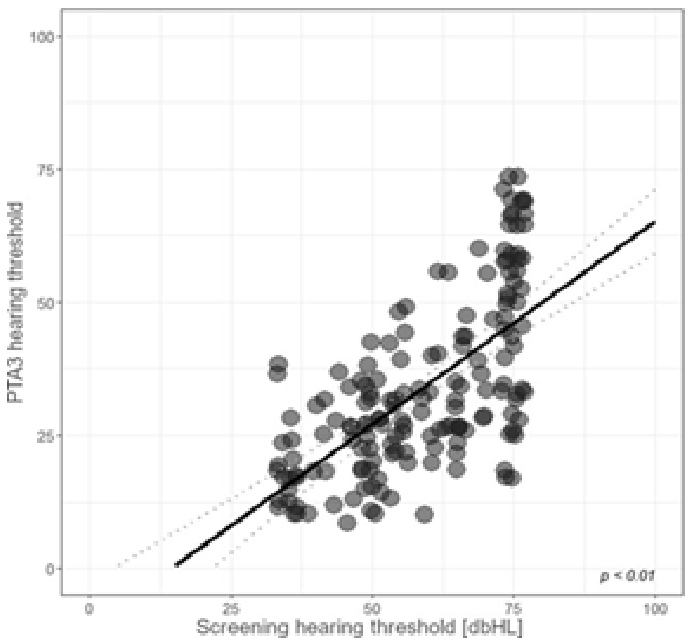

Figure3: Correlation between PTA3 and screening hearing thresholds.

Figure 4 shows the comparison of HHIE-S scores to screening and audiological results. The questionnaire evaluation revealed a moderate handicap in 49%; a severe handicap in 9%; and no handicap in 42% of the participants.

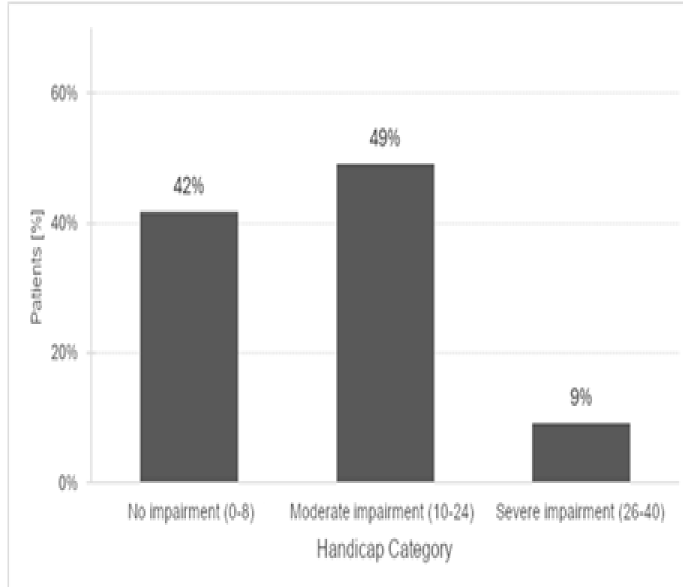

Figure4: Distribution of HHIE-S scores into handicap scores.

Correlation analysis showed a weak correlation between the HHIE-S score and PTA3 (rp = 0.48 ($p < 0.01$)) (Figure 5).

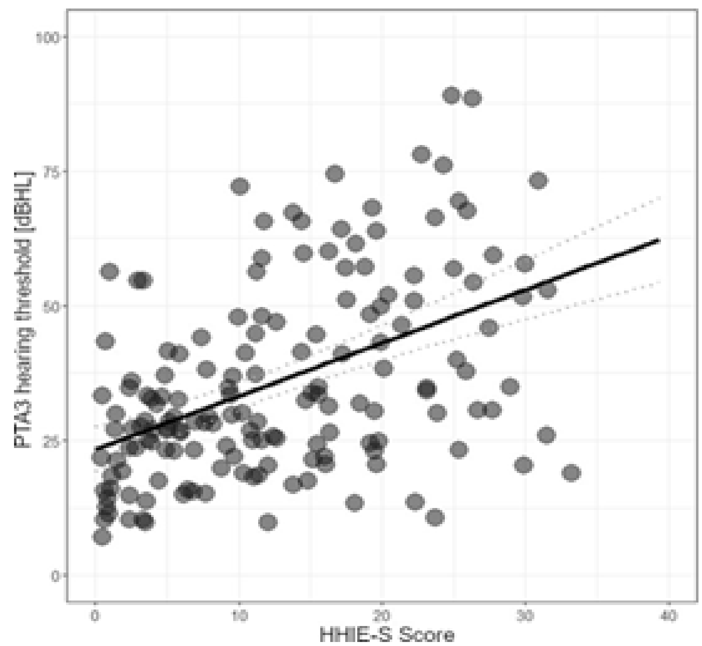

Figure5: Correlation between PTA3 and HHIE-S scores.

Discussion

As outlined previously, the World Report on Hearing [23] revealed an alarmingly high number of individuals worldwide affected by severe hearing loss (approximately 20% of the global population). Among individuals over the age of 60, the estimated prevalence is 65%. Due to the associated reductions in individual quality of life and economic loss caused by reduced productivity and the costs linked to severe hearing loss, the report strongly recommended global hearing screening.

Over the past two decades, the topic of hearing screening in adults has increasingly gained attention from various medical and social research groups, aiming to mitigate the resulting harm to those affected as well as the general public [2,4,5,6,12,24]. Preventive measures can help avoid the damage caused by undetected or untreated hearing loss [8]. However, this requires an effective hearing screening program for adults, followed by timely hearing rehabilitation. Establishing a universal hearing screening program for adults is a significant challenge that will not be easy to overcome. Various approaches have been tested with varying levels of complexity and success. Economic analyses have also been conducted to evaluate costs and potential savings [25-27]. While a PTA would be the standard ideally, implementing this on a large scale is not feasible. Self-assessment using questionnaires, as was done in this study, appears to be a more practical option. The outcomes of hearing-specific questionnaire screenings vary widely but some authors report reliable identification of individuals with hearing loss [19,20,28-30]. The widespread use of smartphones and tablets could also help facilitate hearing screening. Several apps and programs already exist, although their effectiveness – particularly for older adults – remains debated [10,16,19,31-33]. Other methods include screenings with portable devices, whisper tests, and speech-in-noise tests. The feasibility and success of these approaches still require further evaluation [14,33,34].

The implementation and success of adult hearing screening programs must measure up to the global success of NHS. After years of organizational and technical development, NHS has become the gold standard, offering rapid and reliable testing just days after birth [9,35-38]. Applying similar techniques for adult hearing screening appears promising.

The goal of this study was to determine an appropriate screening level for screening in older adults. The results showed that the PTA3 (the average hearing thresholds at 1 kHz, 2 kHz, and 4 kHz) is the most suitable measure. It is well-known that high-frequency hearing loss is particularly prevalent in older age [3]. The correlation between PTA3 thresholds and screening thresholds was quite strong at rp = 0.65. To determine the screening level, audiograms of participants were analyzed to classify them into normal-hearing and individuals with abnormal hearing results. The average hearing screening threshold was 52.5 dBHL but it was found that a screening level of 65 dBHL was necessary to achieve adequate specificity (81.4%) and sensitivity (88.9%). This is crucial for success in field tests. In other studies, lower thresholds for specificity and sensitivity were accepted [10,13,16,17,19,29,34]. Compared to NHS, these thresholds are much lower, leading to more false positives (normal-hearing individuals requiring further testing) and fewer detected cases of hearing loss [35]. However, this is less problematic in adults than in children, as language development is already complete and the hearing loss does not impact developmental processes [37]. Despite this, it remains crucial to avoid the severe consequences of hearing loss. Many individuals are unaware of the fact that timely hearing rehabilitation can address many of these issues [39]. There are, however, reports suggesting that even with screening, success rates for hearing rehabilitation remain limited [40].

The questionnaire results in this study revealed that 58% of participants reported problems in daily life due to reduced hearing ability. These results are comparable to a study conducted in the Czech Republic in 2020–2021, which assessed the sensitivity of the HHIE-S questionnaire and correlated the results with audiometric tests [29]. The relatively low correlation between questionnaire scores and both PTA3 and screening thresholds may stem from the subjective nature of participant self-assessments.

Several things must be considered critically when conducting screenings. The absence of proper soundproofing in testing rooms and participant stress can complicate the screening process. During tests, improperly attached electrodes can lead to high impedance, resulting in measurement errors. Poor fitting in-ear headphones (due to small or narrow ear canals) can produce false-negative results. In addition, some participants reported the acoustic stimuli to be unpleasant, describing them as resembling construction site noises. Ensuring a calm environment (preferably in a soundproof room) and providing clear explanations of the test procedure can help minimize participant discomfort and improve measurement reliability. If these measures are established, the testing can generally be conducted without complications, ensuring reproducible results for further analysis.

Following the successful establishment of this simple screening method for adults, it is now necessary to implement the testing procedure under general conditions, such as in medical practices. The aim would be to ensure that patients with screening results that are indicative of hearing loss are referred for further testing by an ENT specialist, a hearing aid professional or similar. Existing literature suggests that integrating adult hearing screening into the workflows of general medical practices is the most promising approach [11,15,41]. Accordingly, a follow-up study will evaluate the reliability of using the ABR-based hearing screening levels determined in this study under these practical conditions.

Conclusion

There is an urgent need for the implementation of adult hearing screening due to the significant impact of late-detected and inadequately managed hearing loss in older adults. Based on the experiences gained from NHS, an ABR-based test appears to be a suitable option. A screening level of 65 dB has proven particularly effective in achieving high specificity and sensitivity. The practical application should now be tested in general medical practices for individuals aged 60 and older to determine whether this approach can lead to an increase in successful hearing rehabilitation in older adults.

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Appendix

Hearing Handicap Inventory for the Elderly Screening Version (HHIE-S)

Hearing Handicap Inventory for the Elderly – Screening Version (HHIE-S)

Instructions:
Please check "Yes". "Sometimes", or "No" to each of the following items. Do not skip a question if you avoid a situation because of a hearing problem.

	Questions	Yes	Sometimes	No
E-1.	Does a hearing problem cause you to feel embarassed when meeting new people?			
E-2.	Does a hearing problem cause you to feel frustrated when talking to members of your family?			
S-3.	Do you have difficulty hearing when someone speaks in a whisper?			
E-4.	Do you feel handicapped by a hearing problem?			
S-5.	Does a hearing problem cause you difficulty when visiting friends, or relatives or neighbors?			
S-6.	Does a hearing problem cause you to attend religious services less often than you would like?			
S-6.	Does a hearing problem cause you to have arguments with family members?			
S-8.	Does a hearing problem cause you difficulty when listening to TV or radio?			
E-9.	Do you feel that any difficulty with your hearing limits or hampers your personal or social life?			
S-10.	Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?			

Total Score:

HHIE-S scoring and interpretation

Scoring and interpretation:
"Always" = 4 points; "Sometimes" = 2 points; "No" = 0 points. Add up the points for a total score.

Total Score	Handicap Category
0-8	No or limited handicap
10-24	Moderate handicap
26-40	Severe handicap

HHIE-S Categorization (Weinstein, 1990)

Total Score	Auditory Wellness Category
0-2	Excellent
4-6	Good
8-14	Fair
16-22	Poor
24-40	Very poor

Auditory Wellness Category (Humes, 2021)

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