An Australian version of the Acceptable Noise Level test and its predictive value for successful hearing aid use in an older population

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Keywords

Acceptable Noise Level; Hearing aids; Older adults; Hearing impaired; Hearing Aid Use

Abbreviations

ANL = Acceptable Noise Level

BE4FAHL = Better Ear 4 Frequency Average Hearing Loss

BMS = Blue Mountains Study

BNL = Background Noise Level

ILTASS = International Long-Term Average Speech Spectrum

MCL = Most Comfortable Level

NAL = National Acoustic Laboratories

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Abstract

Objective: The Acceptable Noise Level (ANL), a measure of noise tolerance, has been proposed as a predictor for successful hearing aid use. The aims of this study were to obtain normative data, and to evaluate the clinical feasibility and predictive value of an Australian version of the ANL test in an older population.

Design: Repeated ANL measurements were presented diotically using earphones. All participants provided demographic information and hearing aid owners were asked about their aid use.

Study sample: A total of 290 older adults were assessed; 166 participants had a hearing impairment and 96 owned a hearing aid.

Results: The mean ANL was lower than previously reported. While age and gender had no effect on ANL, a significant, but weak, correlation was found between ANL and hearing loss. The test-retest reliability showed the results were clinically unreliable. In addition, the ANL did not predict hours or pattern of hearing aid use.

Conclusions: While the Australian ANL test showed several similar characteristics to previous versions of the test, low test-retest reliability raised questions about its clinical value as a predictor for long-term hearing aid use.

Introduction

Over the last 20 years, the uptake of hearing aids has remained low (Kochkin, 2009). Of the people with hearing impairment who do go on to become hearing aid owners, a number are dissatisfied with their hearing aids. Thanks to improvements in technology, the proportion of dissatisfied hearing aid owners has decreased; however, 17.3% of hearing aid owners remain dissatisfied (Kochkin, 2010). As a recurring reason for dissatisfaction with or non-use of hearing aids is intolerance to background noise (Brooks, 1985; Vuorialho et al, 2006), Nabelek and colleagues (1991) developed the Acceptable Noise Level (ANL) test to quantify a person's background noise tolerance. The ANL was defined as the difference between the most comfortable level when following discourse and the maximal amount of background noise that can be tolerated while still following the discourse. An evaluation of the measure suggested that it was related to hearing aid success: people with a high noise tolerance (i.e., a low ANL) seemed to be successful hearing aid users.

Insert Table 1 near here.

Since its development, the relationship between the ANL and the pattern of hearing aid use has been investigated in four studies summarized in Table 1 (Nabelek et al, 1991, 2004, 2006; Freyaldenhoven et al, 2008b). In these studies, hearing aid users were defined as full-time users if they wore hearing aids whenever needed, part-time users if they wore hearing aids occasionally, and non-users if they had stopped wearing hearing aids (Nabelek et al, 1991). Results demonstrated that full-time users showed a significantly higher tolerance to noise (i.e., lower ANLs) than did part-time and non-users. According to Nabelek et al (2006), an unaided ANL of ≤7 dB predicted full-time hearing aid use, while an ANL of >13 dB suggested future non-use of hearing aids. A clear distinction between part-time and non-users' ANLs was not found. To improve the prediction, two additional approaches were investigated, however the evaluation of the ANL at additional speech levels (Freyaldenhoven et al, 2008b) and the inclusion of the Abbreviated Profile of Hearing Aid Benefit (APHAB) questionnaire (Cox & Alexander, 1995; Freyaldenhoven et al, 2008a) did not enhance the distinction between part-time and non-users. Another problem in these studies was the difficulty predicting the outcome for midrange ANLs between 7 and 13 dB. For example, the most common score of 10 dB, was associated with a 50% chance of successful hearing aid use (Nabelek et al, 2006). Thus, the application of the ANL test as a means of identifying people at risk of difficulties with hearing aid use remained unclear.

Another potential complication with the use of the ANL test is that it is characterized by both large inter- and intra-participant variability. In terms of inter-participant variability, hearing-impaired participants have recorded ANLs from 2 to 27 dB (Nabelek et al, 1991, 2006) and normal-hearing participants have ANLs from -4 to 37 dB (Adams et al, 2010; Brännström et al, 2012; Nichols & Gordon-Hickey, 2012; Rogers et al, 2003). In terms of intra-participant variability, good short-term test-retest reliability has been reported for normal-hearing young adults (Freyaldenhoven et al, 2006; Plyler et al, 2007), normal-hearing middle-aged adults (Brännström et al, 2012), and for hearing-impaired older adults (Plyler et al, 2007). However, correlation analysis was used in these earlier studies, an approach that is not considered appropriate for the assessment of test-retest agreement (Bland & Altman, 1986). More recently, Olsen et al (2012a, 2012b) used the coefficient of repeatability, which is the standard deviation of the differences between test and retest, multiplied by 1.96. They found the coefficient of repeatability for the ANL fell between 6.0 and 8.9 dB for normal-hearing and 6.5 and 8.6 dB for hearing-impaired participants, showing large intra-participant variability.

ANLs are reportedly not influenced by age (Brännström et al, 2012; Moore et al, 2011; Nabelek et al, 2006), degree of hearing loss (Nabelek et al, 1991, 2006), gender (Chen et al, 2011; Nabelek et al, 2006; Rogers et al, 2003) or the content and level of complexity of the target speech signal (Chen et al, 2011; Plyler et al, 2011; von Hapsburg & Bahng, 2006). In contrast, ANLs are reportedly influenced by changes to the initial input level of the target speech signal and the type of background noise signal. An increase in level of the target signal significantly increased the ANLs in normal-hearing (Franklin et al, 2006; Freyaldenhoven et al, 2007) and hearing-impaired participants (Freyaldenhoven et al, 2007, 2008b). Whereas earlier studies found no influence of the type of background speech noise (Crowley & Nabelek, 1996; Nabelek et al, 1991), more recent studies on normal-hearing adults have found that different background speech noises produce different ANLs. For example, the use of speech-shaped noise (Freyaldenhoven et al, 2006) or speech-shaped white noise (Brännström et al, 2012) instead of babble noise, resulted in an average increase in ANLs of 2.1 dB and a decrease of 3.7 dB, respectively.

In view of the ANL test’s potential for predicting hearing aid use and its seeming ease of administration and implementation in a clinical setting, there was interest in establishing an Australian English version of the test. We anticipated that identifying ANLs as either a barrier or facilitator to successful hearing aid use in individual older clients would be useful for directing additional services and counselling to those who are potentially at risk of not using their hearing aids in the future. Because of the effect various test parameters have on the ANL, data from different studies cannot be compared directly. Therefore, the implementation of an ANL test using speech material by Australian talkers required an independent evaluation of its reliability and its potential associations with hearing aid use. Furthermore, the ANL test had to date been assessed using research volunteers, who could be more high-performing than the average age group they represent. As first time hearing aid users with an acquired hearing impairment tend to be older adults, the question arose as to how well the average older clinical population would be able to manage the tasks necessary to complete the ANL test in a reliable and timely manner.

This study aimed to establish normative data for an older population and to evaluate the test-retest reliability and clinical feasibility of an Australian version of the ANL test. For this purpose, ANLs were obtained on 290 participants aged 60 years and over. The potential predictive value of the ANL test for hearing aid use was also investigated in two sub-groups: 96 participants who reported hours of hearing aid use and 57 participants who reported pattern of use, as defined by Nabelek et al. (1991).

Method

Participants

In total, 290 individuals were included in the study, normal-hearing as well as hearing-impaired participants. The participant group consisted of 155 women and 135 men with an average age of 74.7 years (SD = 6.5). The majority of the participants (n = 239) were tested as part of the Blue Mountains Study (BMS), an epidemiological study on vision and hearing targeting the population over 60 years of age in the Blue Mountains area west of Sydney, Australia (Mitchell et al, 2011). As the number of hearing aid owners in the BMS population was small (n = 45), a further 51 hearing aid owners were recruited from the National Acoustic Laboratories' (NAL) database of volunteers. An overview of participants based on location of testing, hearing status, hearing aid ownership, and use is shown in Figure 1.

Insert Figure 1 near here.

Some data were missing for the BMS participants for unknown reasons. Audiograms were available for 264 participants, of whom 166 (79 female, 87 male) had a better ear Four Frequency Average Hearing Level across 500, 1000, 2000 and 4000 Hz (BE4FAHL) of over 25 dB HL. Participants with normal hearing had a median age of 74 years (SD = 5.6), which was slightly younger than participants with a hearing impairment who had an average age of 76.1 years (SD = 6.6). The majority of participants with hearing impairment (n = 102) had a mild loss (26-40 dB BE4FAHL). There were fewer participants with greater degrees of hearing loss: 48 participants had a moderate loss (41-55 dB BE4FAHL), 12 participants had a moderately–severe loss (56-70 dB BE4FAHL), and 4 participants had a severe hearing loss (71-90 dB BE4FAHL). With one exception, all hearing impairments in the better ear were sensorineural. Over 75% of participants had a symmetrical hearing impairment (n = 126), defined as a difference in 4FAHL between ears less than or equal to 10 dB and a difference, at any single frequency, no greater than 20 dB for octave frequencies between 250 and 4000 Hz.

All 290 participants completed the ANL test twice, and provided demographic information and, if they owned hearing aids, information about hearing aid use. Of the 166 participants who had a hearing impairment in the better ear, 96 (41 female, 55 male) owned a hearing aid. Nine participants had hearing aids for less than 1 year, 46 had aid/s for 1 to 5 years, and the remaining 40 participants had owned hearing aid/s for more than 5 years. As shown in Figure 1, hearing aid owners reported their hours of use according to the following categories: 0 or less than 1 hour/week (n = 20); less than 1 hour/day (n = 16); 1-4 hours/day (n = 16); 4-8 hours/day (n = 11) and more than 8 hours/day (n = 32). Pattern of hearing aid use was also categorized, if possible, according to the definition used by Nabelek et al (1991). For the 51 participants tested at NAL, 29 participants reported they were full-time users, wearing their hearing aids whenever needed; 15 stated they used their hearing aids occasionally, making them part-time users; and 7 participants reported they no longer used their hearing aids. Of the 45 BMS study participants who owned hearing aids, 6 participants could be categorised as non-users. These hearing aid owners had stopped using their hearing aids for reasons other than management difficulty or aesthetics and provided reasons such as ‘doesn’t help me to hear’ or ‘problems with own voice’. Thus, there was a total of 13 non-users of hearing aids in the sample: 7 tested at NAL and 6 in the BMS.

Ethical approval for the project was obtained from the Australian Hearing Human Research Ethics Committee for participants assessed at NAL and from the University of Sydney Human Research Ethics Committee for participants tested in the BMS. Written informed consent was obtained from all participants and those assessed at the NAL were offered a small cash gratuity to offset their travel costs.

Stimuli

The speech stimulus used for the ANL test was a looped 5 minute recording of “Flying Hero Class” by Thomas Keneally, read by a native Australian male speaker. The background babble-noise was a mixture of four female and four male talkers. Both recordings were filtered to match the International Long-Term Average Speech Spectrum (ILTASS) by Byrne et al (1994) and are available on a CD (Keidser et al, 2002). This speech material was chosen as it used Australian English speakers and was available in audiology clinics.

Equipment

The CD was played on a Yamaha CDX-530 compact disc player and routed through a two-channel Madsen OB822 diagnostic audiometer. A custom made switching box allowed for the change between the standard (monotic) audiometer configuration, used to perform pure tone audiometry, and the diotic ANL presentation. Both the speech and the combined speech and noise signal were presented diotically through both left and right TDH-39 earphones. This set-up was chosen as it was considered easier to replicate in an audiology clinic and not dependent on head movements, compared with free field assessment. During the ANL assessment, participants adjusted the level of the signal by pressing buttons labelled 'up' and 'down' on a custom-made remotely controlled attenuator. Another custom-made switching box was used to set whether the level of the speech or the noise signal would be adjusted when using the attenuator control. The audiometer was calibrated to comply with International Electrotechnical Commission standards for pure-tone testing (IEC 60645-1). The equipment used for ANL measurements was calibrated by measuring the level of ILTASS-shaped random noise delivered to the TDH-39 earphones using a Brüel & Kjær 2235 Precision Sound Level Meter and a Brüel & Kjær 4152 artificial ear with a Brüel & Kjær 4144 pressure microphone. All audiological testing took place in a sound-treated room.

ANL assessment

The ANL instructions were essentially the same as used by Nabelek et al (2004), with reiteration of the final step for clarification. Written instructions for the tasks were provided, which were also reinforced verbally. The instructions can be found on http://informahealthcare.com/loi/ija. All participants were asked if they had any questions about the tasks and these were addressed. Once the procedure started, the audiologist would indicate on the written instruction sheet which task the participant was requested to complete. The speech signal was presented to both ears using earphones. First, the participant was asked to turn the volume up until the level of the story was too loud, then turn it down until it was too soft, and then set the volume to their most comfortable level (MCL). The story continued at their selected MCL and background noise was added to both ears. The participant was asked to turn up the level of the background noise until it was too loud, turn down the level of the noise until the story became very clear, and lastly to choose the background noise level (BNL) which was the most they could put up with “for a long time” while following the story. Despite the potential for individual differences in the interpretation of these instructions, as mentioned by Edwards (2011), the ANL task was described as reported by Nabelek et al (2004) to allow for comparison of the results with that study. A 5 dB step size was used to set the “too loud” and “too soft” levels for speech and noise, and a 1 dB step size was used for selecting the MCL and BNL. Participants were asked to complete the procedure twice and the average was used as their ANL result. The time it took to complete the assessment was recorded for 48 NAL participants, starting the timer when the instructions were given and stopping it when the ANL had been obtained.

Data analysis

Statistical analyses were performed using Statistica version 10. Whereas Levene’s test accepted homogeneity of variance between all groups investigated in this study, the Lilliefors test rejected the assumption of normality of the ANL, MCL, BNL, age and BE4FAHL data. However, given the high number of observations (>100) in this study, the breach of the normality assumption has no effect on the t or F-statistics (Lumley et al, 2002), and therefore parametric tests were used.

Correlation analyses were used to investigate the relationships between the ANL, MCL, and BNL values; BE4FAHL; and age. To assess ANL differences across gender and hearing status and to evaluate the difference in ANL, MCL and BNL for participants with normal hearing and hearing impairment, tests for independent samples were used. The clinical feasibility of the ANL was assessed using the intra-participant standard deviations, the coefficient of repeatability, and by performing a correlation analysis between the duration of the ANL assessment and age. A multiple regression analysis was performed to investigate whether more reliable performers could be identified from the absolute difference between both ANL measures. As the absolute difference values showed a one-tailed distribution, these were transformed with a logarithmic function before being used as the dependent factor, with age, gender, and hearing loss as independent variables. One-way analyses of variance (ANOVAs) were used to assess the predictive value of the ANL using the categorical variables hours of hearing aid use and pattern of use. Correlation analyses including a categorical variable were performed using the Spearman's rank order correlation test.

Results

Normative data

All 290 older adults performed the ANL procedure twice, and the results were averaged to obtain their ANL. The ANL ranged from -11 to 27.5 dB with a mean of 4.1 dB and a standard deviation of 5.5 dB (see Figure 2). There was a significant, but weak, correlation between the average ANL and average MCL and BNL values. Higher ANL values were associated with higher MCL and lower BNL values, respectively ($r = 0.26$, $p < 0.05$; $r = -0.25$, $p < 0.05$). In this older population, no significant association was found between the ANL and age or gender ($r = 0.05$, $p = 0.37$; $t(288) = -0.23$, $p = 0.82$). However, there was a significant, though very weak, correlation between the ANL and BE4FAHL across the sample ($r = 0.14$, $p = 0.02$), with ANL increasing with increasing degree of hearing loss (see Figure 3).

Insert Figures 2 and 3 near here.

The average MCL and BNL values were both significantly higher for participants with hearing impairment than for participants with normal hearing ($t(262) = 9.1$, $p < 0.0001$; $t(262) = 7.9$, $p < 0.0001$), but there was no significant difference in ANLs for these participants ($t(262) = -1.1$, $p = 0.25$). Interestingly, the mean ANLs obtained from participants tested at NAL (6.5 dB) was significantly higher than that obtained from BMS participants (3.7 dB) ($t(288) = -3.0$, $p = 0.003$). The standard deviation for the two groups was 5.4 and 5.7 dB, respectively, showing a similar spread of results. Given the significant correlation between ANL and BE4FAHL reported above, the significantly higher ANL for participants tested at NAL is most probably explained by their higher degree of hearing loss (42.4 dB compared to 29.4 dB).

Clinical feasibility

Insert Figure 4 near here.

The coefficient of repeatability for the ANL in this population was 8.5 dB. The correlation between the first and second ANL measures was significant, but moderate ($r = 0.73$, $p < 0.05$), suggesting that about 50% (r^2) of the variation in data was unaccounted for (Figure 4). Test-retest differences fell within 3 dB for half of the participants, but reached as high as 20 dB for other participants. The average intra-participant standard deviation was 2.2 dB, with 33% of participants producing an intra-participant standard deviation greater than the 95% confidence value of the mean. A third of this older population produced test-retest differences larger than twice the standard deviation, or 4 dB or greater, showing poor test-retest reliability. Multiple regression analysis showed participants with greater test-retest differences could not be identified on the basis of their age, gender, or degree of hearing loss ($F(3, 198) = 2.1$, $p = 0.1$).

To further evaluate the clinical feasibility of the test, the time it took participants tested at NAL to complete both ANL measures was assessed. Of the 51 participants, 48 had the duration recorded for both measures. On average, the first ANL took 6.3 min (SD = 1.8), ranging from just under 4 to over 13.5 min. The mean duration of the second ANL did not include repetition of the instructions and was therefore shorter (just under 3 min; SD = 0.8), ranging from just over 1.5 to under 5.5 min. The correlation between the mean duration of the two measures and age was weak but statistically significant ($r = 0.31$, $p < 0.05$), with time taken to complete the test increasing with increasing age. Overall, these findings suggest that while the duration of the ANL test seems to make it clinically feasible, its test-retest reliability seems questionable.

Predictive value

To evaluate the predictive value of the ANL test, results were compared with reported hours of use and pattern of use categories. Information about hours of hearing aid use was collected from participants both in the BMS and at NAL (n = 95). A one-way ANOVA revealed no significant difference in ANLs for the different hours of hearing aid use categories ($F(4,90) = 0.12$, $p = 0.97$).

The pattern of hearing aid use was known for 57 hearing aid owners. For this subgroup, there was a significant and high correlation between pattern of use category and hours of hearing aid use ($r = -0.89$, $p < 0.05$). Most full-time users used their devices more than 8 hours/day, while most part-time users used their devices a few hours/day. As with hours of hearing aid use, a one-way ANOVA demonstrated that ANLs did not differ significantly for the different patterns of use ($F(2,54) = 1.96$, $p = 0.15$) (see Figure 5). Combining the part-time and non-user groups into an “unsuccessful” category, as suggested in Nabelek et al (2006), showed a trend toward a significantly different ANL for successful (full-time) and unsuccessful users (t(55) = 2.0, p = 0.05, 95% CI -0.2 to 5.70). Contrary to previous findings, the ANL for part-time (mean = 4.9 dB; SD = 5.2 dB) and non-users (mean = 4.5 dB; SD = 5.1 dB) was lower than for the full-time users (mean = 7.5 dB; SD = 5.7 dB).

Insert Figure 5 near here.

There was no significant difference in the average BE4FAHL for participants in the three pattern of use categories (F (2, 54) = 2.4; p = 0.10). However, when comparing the “successful” and “unsuccessful” users, it was found that the successful users had a significantly higher mean BE4FAHL (44.4 dB) than the group containing part-time and non-users (39.6 dB) (t(55) = 2.1, p = 0.04). The difference in ANLs measured across pattern of use is thus consistent with the earlier observations that the ANL seems to increase with increasing hearing loss.

Discussion

This study set out to obtain normative data in older adults for a new Australian version of the ANL test, evaluate its reliability, and check its clinical feasibility. The predictive value for hearing aid use was further investigated in subgroups of participants. The study differs from previous large-scale studies of the ANLs by including a broad clinical population, encompassing adults over 60 years of age with a wide range of hearing sensitivity.

Normative data

Participants evaluated with the Australian ANL test recorded a lower mean than reported in most other studies (by about 5-6 dB), though the spread of results was similar (Adams et al, 2010; Crowley & Nabelek, 1996; Freyaldenhoven et al, 2006; Nabelek et al, 1991; Plyler et al, 2007). Potential reasons for the lower mean result in this study are most likely to be procedural or extrinsic in nature. In terms of procedure, the mode of delivery used in this study differs from most other studies in which speech and noise were either presented unilaterally through earphones, or bilaterally in the free field. In this study stimuli were presented diotically (the same signal in both ears) through earphones. Harkrider and Smith (2005) compared different modes of delivery and found a mean difference of 2 dB between monotic (both signals in the same earphone) and dichotic presentation (speech presented in one earphone and noise presented in the other), supporting the idea that different modes of delivery could influence the ANL. In addition, different background noise signals have been shown to affect the ANL result by up to 3.7 dB (Freyaldenhoven et al, 2006; Brännström et al, 2012) and it is therefore possible that the noise stimulus used in the present study also influenced the results. In terms of extrinsic reasons for the lower ANLs in this study compared to others, it may be that cultural differences in the acceptance of background noise influenced the ANL. This has previously been suggested by Brännström et al (2012) who found a statistically significant difference in ANL of 5 dB, on average, for two groups of 40 adults with normal hearing in two countries using the same instructions, set-up, and materials.

Consistent with previous research, the ANLs obtained in older adults using the Australian version were independent of age (Brännström et al, 2012; Moore et al, 2011; Nabelek et al, 2006) and gender (Chen et al, 2011; Nabelek et al, 2006; Rogers et al, 2003). However, contrary to prior findings (e.g. Nabelek et al, 2006), a weak but statistically significant correlation was evident between ANL and hearing loss. The relationship was strongest for participants with an average hearing loss greater than 45 dB who almost all obtained positive ANLs (see Figure 3). When this group of participants was excluded from the correlation analysis, the effect of hearing loss became non-significant ($r = 0.04$, $p = 0.54$). In the only prior study examining the correlation between ANL and degree of hearing loss in a large sample, Nabelek et al (2006) found no significant correlation (r = -0.12, p = 0.16) in 191 hearing aid owners with a similar range of hearing loss to the participants in the present study. Nabelek et al (2006) possibly included a smaller proportion of participants with average hearing loss greater than 45 dB than included in the present study and this may explain the difference in findings. Assuming participants used an intelligibility, rather than a loudness criterion to select the noise level (e.g. Edwards, 2011), the suggestion that people with more severe hearing loss would require better signal-to-noise ratios to ‘follow the story without becoming tense or tired’ seems compelling, and would agree with past findings (Humes, 2002; Saunders & Forsline, 2006).

The relationship between degree of hearing loss and ANL (i.e., greater hearing loss, higher ANLs) provides a possible explanation for the significant differences observed in ANLs between participants tested at NAL versus BMS participants, who presented with significantly different degrees of hearing loss.

Clinical feasibility

The coefficient of repeatability in this study was 8.5 dB, showing large intra-participant variability between both ANL measures. This result fell between 6.0 and 8.9 for normal-hearing and 6.5 and 8.6 dB for hearing-impaired participants reported in Olsen et al (2012a, 2012b). In the present study, one-third of participants produced test-retest differences above the 95% confidence interval. Those with a large difference between test and retest ANL results could not be identified from personal or audiological data, suggesting that, to obtain a valid ANL, more than two measurements may be needed.

Based on the duration of the test assessed in a subsample of participants, the ANL test seemed clinically feasible. On average, it took participants less than 10 minutes to complete the task twice, with older participants needing more time (up to 16 minutes). However, not all older people can be expected to do the test. Although there is no record of the numbers or the specific reasons in the BMS data set, the authors know that some participants seen in that sample were unable to complete the task. As only complete data were used, they were not included in this study. The applicability of the ANL is also limited to those with relatively good speech discrimination in quiet. One participant seen at NAL was excluded from the study as he was unable to follow the story in quiet, and therefore unable to complete the procedure. Other participants may not have voiced their concerns about the task, which means different individuals could use different criteria to set the level of the noise, as observed by Edwards (2011). That is, while some participants may follow instructions literally and select levels based on their ability to follow and understand speech word-for-word, others may select levels based on listening effort or comfort, irrespective of whether speech could be understood. Such differences may contribute to the high degree of variability generally seen in ANL data.

Predictive value

Contrary to previous findings, no relationship was found between ANL and hours of use (Nabelek et al, 2006) or successful hearing aid use (Nabelek et al, 1991, 2004, 2006; Freyaldenhoven et al, 2008b). The mean ANL for full-time users in this study was similar to that of full-time users in previous studies (Nabelek et al, 1991, 2004, 2006; Freyaldenhoven et al, 2008b), however the part-time and non-users performed differently. In previous studies part-time and non-users produced significantly higher ANL values than full-time users (Nabelek et al, 1991, 2006; Freyaldenhoven et al, 2008b); in the present study, they obtained lower ANLs than full-time users (borderline significant). There are two possible reasons for the discrepancy in findings. Firstly, there were differences in participants' hearing aid experience across studies. The developers of the ANL test have focused on participants with no more than 3 years of hearing aid experience (Nabelek et al, 2006), whereas participants in this study had, on average, a much longer history of use, with one-third of the participants owning their devices for more than 10 years. Secondly, the participants who were part-time and non-users of hearing aids in the present study had less hearing loss than the full-time users. As mentioned above, ANL was correlated with degree of hearing loss such that it increased as the loss increased. In previous ANL studies (Freyaldenhoven et al, 2008b; Nabelek et al, 1991, 2004), there were no significant differences in hearing loss between user groups.

Methodological limitations and future directions

As this study was set up primarily to evaluate normative data and the clinical feasibility of a new Australian version of the ANL test, a retrospective study was considered appropriate. The ANL was assessed twice in a single assessment session. More research is necessary to understand the reasons for the large test-retest differences found. Also, the hint of a correlation between ANL and hearing loss is interesting and should be further investigated in larger numbers of participants with an equal distribution of different degrees of hearing loss. Finally, future studies should take a more prospective approach to investigate the potential predictive value of the ANL test for hearing aid use.

Conclusion

This study evaluated the clinical feasibility of an Australian version of the ANL test in 290 adults over 60 years of age. The ability of the test to predict successful hearing aid use was further investigated in 96 hearing aid owners who reported hours of use and in 57 individuals who had their pattern of aid use recorded. Our findings do not support lower ANLs as a predictor of successful hearing aid use as the literature in this field had previously indicated. Normative data for this population showed a lower mean ANL than seen previously, possibly due to procedural and extrinsic factors. While age and gender could not predict the ANL, there was a significant tendency for people with more severe hearing loss to obtain higher ANLs than people with normal hearing and mild hearing loss. Although the duration of the test suggested it was clinically feasible, its test-retest reliability was poor. In summary, the findings of this study do not support the use of the ANL test in a clinical setting to identify possible barriers or facilitators to hearing aid use in the older population.

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Declaration of interest

The authors report no declarations of interest.

References

Adams, E.M., Gordon-Hickey, S., Moore & R.E., Morlas, H. 2010. Effects of reverberation on acceptable noise level measurements in younger and older adults. *Int J Audiol*, 49, 832-838.

Bland, J.M., & Altman, D.G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, 327, 307-310

Brännström, K.J., Lantz, J., Nielsen, L.H. & Olsen, S.Ø. 2012. Acceptable noise level with Danish, Swedish, and non-semantic speech materials. *Int J Audiol,* 51(3), 146-156.

Brooks, D.N. 1985. Factors relating to the under-use of postaural hearing aids. *Br J Audiol*, 3, 211-217.

Byrne, D., Dilon, H., Tran, K., Arlinger, S., Wilbraham, K. et al. 1994. An international comparison of long-term average speech spectra. *J Acoust Soc Am*, 96, 2108-2120.

Chen, J., Zhang, H., Plyler, P.N. & Cao, W. 2011. Development and evaluation of the Mandarin speech signal content on the acceptable noise level test in listeners with normal hearing in mainland China. *Int J Audiol*, 50, 354-360.

Cox, R.M. & Alexander, G.C. 1995. The abbreviated profile of hearing aid benefit. *Ear Hear*, 16, 176-186.

Crowley, H.J. & Nabelek, I.V. 1996. Estimation of client-assessed hearing aid performance based upon unaided variables. *J Speech Hear Res*, 39, 19-27.

Edwards, B., 2011. Starkey Research, and How Do You Define Success with Hearing Aids? *Audiology Online Interviews*, [online]. Available at: <http://www.audiologyonline.com/interview/interview_detail.asp?interview_id=575> [Accessed 25/3/2013].

Franklin, C.A., Jr., Thelin, J.W., Nabelek, A.K. & Burchfield, S.B. 2006. The effect of speech presentation level on acceptance of background noise in listeners with normal hearing. *J Am Acad Audiol*, 17, 141-146.

Freyaldenhoven, M.C., Smiley, D.F., Muenchen, R.A. & Konrad, T.N. 2006. Acceptable noise level: reliability measures and comparison to preference for background sounds. *J Am Acad Audiol*, 17, 640-648.

Freyaldenhoven, M.C., Plyler, P.N., Thelin, J.W. & Hedrick, M.S. 2007. The effects of speech presentation level on acceptance of noise in listeners with normal and impaired hearing. *J Speech Lang Hear* Res, 50, 878-885.

Freyaldenhoven, M.C., Nabelek, A.K. & Tampas, J.W. 2008a. Relationship between acceptable noise level and the abbreviated profile of hearing aid benefit. *J Speech Lang Hear Res*, 51, 136-146.

Freyaldenhoven, M.C., Plyler, P.N., Thelin, J.W. & Muenchen, R.A. 2008b. Acceptance of noise growth patterns in hearing aid users. *J Speech Lang Hear Res*, 51, 126-135.

Harkrider, A.W. & Smith, S.B. 2005. Acceptable noise level, phoneme recognition in noise, and measures of auditory efferent activity. *J Am Acad Audiol*, 16, 530-545.

Humes, L.E. 2002. Factors underlying the speech-recognition performance of elderly hearing-aid wearers. *J Acoust Soc Am*, 112, 1112-1132.

International Standards Organisation. 2012. IEC 60645-1. Electroacoustics - Audiometric equipment - Part 1: Equipment for pure-tone audiometry.

Keidser, G., Ching, T., Dillon, H., Agung, K., Brew, C. et al. 2002. The National Acoustic Laboratories' (NAL) CDs of Speech and Noise for Hearing Aid Evaluation: normative data and potential applications. *Aust NZ J Audiol*, 24(1), 16-35.

Kochkin, S. 2009. MarkeTrak VIII: 25 year trends in the hearing health market. *Hearing Review*, 11, 12-31.

Kochkin, S. 2010. MarkeTrak VIII: Consumer satisfaction with hearing aids is slowly increasing. *Hear J*, 63, 19-32.

Lumley, T., Diehr, P., Emerson, S. & Chen, L. 2002. The Importance of the Normality Aussmption in Large Pubic Health Data Sets. *Annu Rev Publ Health*, 23, 151-169.

Mitchell, P., Gopinath, B., Wang, J.J., McMahon, C.M., Schneider, J., et al. 2011. Five-year incidence and progression of hearing impairment in an older population. *Ear Hear*, 32, 251-257.

Moore, R., Gordon-Hickey, S. & Jones, A. 2011. Most comfortable listening levels, background noise levels, and acceptable noise levels for children and adults with normal hearing. *J Am Acad Audiol*, 22, 286-293.

Nabelek, A.K., Tucker, F.M. & Letowski, T.R. 1991. Toleration of Background Noises: Relationship with Patterns of Hearing Aid Use by Elderly Persons. *J Speech Hear Res*, 34, 679-685.

Nabelek, A.K., Tampas, J.W. & Burchfield, S.B. 2004. Comparison of speech perception in background noise with acceptance of background noise in aided and unaided conditions. *J Speech Lang Hear Res*, 47, 1001-1011.

Nabelek, A.K., Freyaldenhoven, M.C., Tampas, J.W., Burchfield, S.B. & Muenchen, R.A. 2006. Acceptable noise level as a predictor of hearing aid use. *J Am Acad Audiol*, 17, 626-639.

Nichols, A.C. & Gordon-Hickey, S. 2012. The relationship of locus of control, self-control, and acceptable noise levels for young listeners with normal hearing. *Int J Audiol*, 51, 353-359.

Olsen, S.Ø., Nielsen, L.H., Lantz, J. & Brännström, K.J. 2012a. Acceptable noise level: Repeatability with Danish and non-semantic speech materials for adults with normal hearing. *Int J Audiol*, 51, 146-156.

Olsen, S.Ø., Lantz, J. Nielsen, L.H. & Brännström, K.J. 2012b. Acceptable noise level (ANL) with Danish and non-semantic speech materials in adult hearing-aid users. *Int J Audiol,* 51, 678-688.

Plyler, P.N., Madix, S.G., Thelin, J.W. & Johnston, K.W. 2007. Contribution of high-frequency information to the acceptance of background noise in listeners with normal and impaired hearing. *Am J Audiol,* 16, 149-156.

Plyler, P.N., Alworth, L.N., Rossini, T.P. & Mapes, K.E. 2011. Effects of speech signal content and speaker gender on acceptance of noise in listeners with normal hearing. *Int J Audiol,* 50, 243-248.

Rogers, D.S., Harkrider, A.W., Burchfield, S.B. & Nabelek, A.K. 2003. The influence of listener's gender on the acceptance of background noise. *J Am Acad Audiol,* 14, 372-382.

Saunders, G.H. & Forsline, A. 2006. The Performance-Perceptual Test (PPT) and its relationship to aided reported handicap and hearing aid satisfaction. *Ear Hear,* 27, 229-242.

von Hapsburg, D. & Bahng, J. 2006. Acceptance of background noise levels in bilingual (Korean-English) listeners. *J Am Acad Audiol,* 17, 649-658.

Vuorialho, A., Sorri, M., Nuojua, I. and Muhli, A. 2006. Changes in hearing aid use over the past 20 years. *Eur Arch Otorhinol,* 263, 355-360.

List of Tables

List of Legends

Figure 1. Breakdown of participant numbers by location of testing, hearing status, hearing aid ownership and use.

Figure 2. Distribution of the ANL results (dB) with the fitted curve showing the normal distribution.

Figure 3. The relationship between Average ANL (dB) and hearing loss, determined by BE4FAHL (Better Ear Four Frequency Average Hearing Loss). The line shows the best linear fit to data (n = 264).

Figure 4. The relationship between test and retest ANLs (dB) together with the fitted regression line (full) and unity line (dashed) (n = 290).

Figure 5. Average ANL results across the pattern of use groups. The bars show 95% confidence intervals.

Tables

Table 1

Study	Nabelek et al (1991)	Nabelek et al (2004)	Nabelek et al (2006)	Freyaldenhoven et al (2008b)
Stimuli	Female voice Babble (12 sp)	Arizona Travelogue Babble from revised SPIN	Arizona Travelogue Babble from revised SPIN	Arizona Travelogue Babble from revised SPIN
Delivery	Monaural earphone to preferred ear	Sound field	Sound field	Sound field
ANL (full-time)	7.4 (5.1) *15*	7.5 (2.7) *41*	7.7 (3.0) *69*	6.8 (4.4) *25*
ANL (part-time)	12.7 (7.0) *15*	11.8 (2.4) *9*	13.5 (3.9) *69*	10.9 (4.2) *21*
ANL (non-use)	14 (4.7) *15*		14.4 (4.0) *53*	12.9 (6.7) *26*