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Review

Acceptable noise level as a deciding factor for prescribing hearing aids for older adults with cochlear hearing loss — A scoping review

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Abstract

Older adults often find it difficult to perceive speech, especially in noisy conditions. Though hearing aid is one of the rehabilitative devices available to older adults to alleviate hearing loss, some of them may experience annoyance through hearing aid and hence reject it, may be due to circuitry noise and/or background noise. Acceptable noise level is a direct behavioural measure to estimate the extent of how much a person is able to put up with noise while simultaneously listening to speech. Acceptable noise level is a central auditory measure and it is not influenced by age, gender, presentation level or speaker. Using this measure, we can quantify the annoyance level experienced by an individual. This information is of utmost importance and caution should be paid before setting the parameters in hearing aid, especially for those who are unable to accept noise. In this review article, an attempt has been made to document how to optimize the hearing aid program by setting parameters such as noise reduction circuit, microphone sensitivity and gain. These adjustments of parameters might help to reduce rejection rate of hearing aids, especially in those individuals who are annoyed by background noise.

Keywords: Annoyance; Amplification; Speech perception in noise; Older adults; Hearing impairment

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Hearing loss in the elderly population is most common due to presbycusis and other related systemic illness. According to World Health Organisation (WHO) global estimates on prevalence of hearing loss in 2012, approximately one-third of persons above 65 years are affected by disabling hearing loss. There are 164.5 million persons of above 65 years with disabling hearing loss, i.e. 33% of the world's population above 65 years (WHO, 2012). Hearing aids are the major form of rehabilitation to older adults with sensorineural hearing loss. However, the speech perception of older adults through hearing aids varies depending on a number of factors.

1. Speech perception in noise by older adults with hearing loss

Cochlear hearing impairment individuals often complain of understanding speech, especially in background noise. Frequency selectivity is usually reduced in individuals with cochlear hearing loss. In addition, temporal resolution is impaired, especially in advanced age accompanied with hearing loss (Glasberg and Moore, 1989). There are several researchers who studied speech recognition in cochlear hearing loss at different signal-to-noise ratios (SNRs) (Glasberg and Moore, 1989; Festen, 1987; Festen and Plomp, 1990; Plomp, 1994; Festen, 1993; Moore, 1995; Grant and Walden, 2013). Their results suggest that individuals with cochlear hearing loss required higher signal-to-noise ratio (SNR) levels to achieve same performance as normal hearing individuals. In addition, difference in speech recognition threshold (SRT) for normal and hearing-impaired individuals varied greatly depending on the nature of the background noise. When the background noise used was speech-shaped noise, the speech recognition threshold in noise (SRTn) difference between normal and hearing-impaired individuals ranged from 2 to 5 dB (Glasberg and Moore, 1989; Plomp, 1994). Whereas, in other background noise such as single competing talker, time-reversed talker or an amplitude-modulated noise, the difference in SRTn was much larger, ranging from about 7 dB up to about 15 dB (Souza and Turner, 1994; Peters et al., 1998). Thus, speech recognition in noise for cochlear hearing loss individuals varies based on the type of background noise, which masks the temporal and spectral contents of speech. Further, in case of informational masking such as single talker and four talker babble, individuals with cochlear hearing impairment fail to take advantage of “dips” in the competing voice. These dips may be of two types: temporal and spectral. Temporal dips are momentary fluctuations in overall signal-to-noise ratio, especially during brief pauses in speech or during production of low energy sounds. In the region of temporal dips, the signal strength is found to be relatively higher than that of background noise and this allows brief ‘glimpses’ to be obtained from the target speech. The spectral dips arise because the spectrum of the target speech is usually different from that of the background speech measured over any short interval. Although parts of the target spectrum may be completely masked by the background, other parts may be hardly masked at all. Thus, parts of the spectrum of the target speech may be “glimpsed” and used as cue to follow speech in competing noise. Studies have reported possible factors in the reduction of speech recognition in noise (Van Tassel, 1993). Cochlear hearing loss subjects have broadened auditory filters. Wider auditory filters do not mean that it removes information from speech; rather it impedes the transfer of spectral and temporal information. It can be expected that spectral peaks and valleys in stimulus are smoothed out in those individuals with sensorineural hearing loss (SNHL). In addition, upward spread of masking is common i.e., the higher frequency components of speech are masked by the higher amplitude of vocalic sounds or maskers of low frequencies, which is found to be one of confronting factors in SNHL. It was also speculated that only few auditory filters are available for analysis but noise accompanied with stimulus taxes these available filters such that noise accumulates in functioning filters leading to reduced recognition in lesser SNRs. It infers that older adults find it difficult to follow speech in adverse listening conditions. One among the rehabilitative device available to them is hearing aid. There are several measures to assess the aided performance from them. Speech recognition threshold is one such measure which reflects the aided benefit. In addition, outcome measurement scales are used to document the satisfaction index from hearing aid. Unfortunately, there was no relationship between the score on speech intelligibility in noise and his or her real world benefit and/or satisfaction with hearing aids. Majority of hearing aid users reject their device because of background noise through they have had good recognition scores (Kochkin, 2010). It is of utmost importance to measure the amount of annoyance experienced by the hearing impaired subject.

2. Estimation of annoyance towards noise using ANL

Acceptable noise level is the measure of whether the subject is able to put up with noise while simultaneously listening to speech at their most comfortable listening level (Nabelek et al., 1991). This method of quantifying background noise acceptance is termed “acceptable noise level” (ANL). Based on acceptance towards noise, ANL is classified into three groups. Individuals who receive ANL values of <7 dB HL, >13 dB HL and between 7 dB HL and 13 dB HL were termed as low, high and average ANL groups, respectively. The clinical consequence of ANL on hearing impaired individuals was demonstrated (Nabelek et al., 1991). Those who received low ANLs (<7 dB HL) tend to accept more noise, with high potential to become successful hearing aid users. Conversely, hearing impaired individuals with high ANLs (>13 dB HL) tend to accept less noise relative to their counterparts. They are less likely to become successful hearing aid users and may face problems often with the usage of hearing aid. ANL is driven by central auditory structures (Harkrider and Tampas, 2006; Tampas and Harkrider, 2006). The role of the auditory efferent system on acceptable noise level was examined in a study (Harkrider and Smith, 2005). Monotic (speech and noise presented to only one ear) and dichotic (speech presented to one ear and noise presented to the other ear simultaneously) ANLs were measured for 31 adults with normal hearing and compared to contralateral suppression of transient evoked otoacoustic emissions, phoneme recognition in noise, middle ear impedance measures, and ipsilateral and contra lateral acoustic reflex thresholds. Results indicated that monotic ANLs were correlated with dichotic ANLs. However, there was no relation between middle ear impedance measures, acoustic reflex thresholds, contra lateral suppression of otoacoustic emissions, or phoneme recognition in noise to either monotic or dichotic ANLs. The authors suggest that ANL may be mediated by non-peripheral auditory system. They further suggest that ANL may be mediated, in part, beyond the level of the superior olivary complex where binaural processing initially occurs within the central auditory nervous system. Higher auditory centres using evoked potentials in participants having low and high ANLs was examined (Tampas and Harkrider, 2006). The results revealed that in subjects with low ANL, the amplitude difference become increasingly more remarkable in wave V of the auditory brainstem response (ABR), middle latency response (MLR) and late latency response (LLR). The amplitude of each response was larger in high ANL group than those with low ANL. Conversely, in latency of each response was earlier in low ANL than high ANL. This could be due to the stronger efferent mechanism such that sensory inputs are suppressed and/or central afferent mechanism is less active. The physiological activity of peripheral and central auditory nervous system was investigated in participants with normal hearing having low- and high-ANL (Harkrider and Tampas, 2006). The results indicated no difference in otoacoustic emission and ABR peaks of I and III. However difference emerges in wave V component of ABR, and Na and Pa components of MLR suggesting that ANL is of central origin. In yet another similar study, the relationship between behavioural measure of ANL and its physiological mechanism in the normal hearing participants was studied (Vishal and Hemanth, 2015). They concluded that the slope of VA in quiet and in noise conditions was found steeper in low ANL group indicating stronger auditory afferent and efferent auditory pathway at the central level. Still the question arises is larger activity of noise [electroencephalogram (EEG)] obscures signal strength (response time locked to stimulus), which reflected in the amplitude of the response waveform. The following research question was taken up and the relationship between acceptable noise level and electrophysiologic auditory brainstem and cortical signal-to-noise ratios was investigated (Hemanth et al., 2014). The physiological findings continue to suggest that the higher processing centers in the upper brainstem to the cortex is involved in the behavioural acceptance of more noise (low ANL) compared to those who are not willing to accept noise (high ANL) and is not a reflection of the signal to noise inherent in the evoked potential averaging process.

2.1. Factors influencing ANL

2.1.1. Language

ANL increased significantly using reversed or unfamiliar language as speech signal compared to intelligible speech (Goldman, 2009). In a similar line of study, it was reported that non semantic versions of ANL generate unreliable results that cannot predict hearing aid use (Olsen et al., 2012). ANL was examined using speech passage of different languages and their babbles in multi-talkers as background noise (Shi et al., 2015). Participants included 55 adult listeners aged from 19 to 41 years, in which 15 were English monolingual, 16 Russian-English bilingual, and 24 Spanish-English bilingual listeners. They found that Russian-English bilingual listeners yielded significant higher ANL values (by 4−5 dB) than the other listeners. All listeners, regardless of their language background, yielded significantly higher ANL values with Spanish than the English signal, although the difference was negligible. The language of the babble significantly interacted with the number of talkers, but only in Russian-English bilinguals, for whom 12-talker Spanish babble yielded higher ANL values by 1.5 dB than 12-talker English babble. This finding supports the notion that ANL is language independent.

2.1.2. Type and preference of noise

There was no effect of type of noise on ANL (Nabelek et al., 1991). This was supported by another study in which confronting variables of noise was constructively varied and its effect on ANL was observed (Crowley and Nabelek, 1996). They found mean ANL difference yielded between 12 speaker babble and steady state speech shaped noise but this did not reach significance.

2.1.3. Presentation level

ANL was measured at eight fixed presentation levels ranging from 40 dB HL to 75 dB HL in steps of 5 dB, using speech stimuli (sentences) to determine ANL growth in normal hearing and hearing impaired individuals (Freyaldenhoven et al., 2007). Participants were 24 normal hearing subjects and 46 hearing impaired subjects. The results revealed that global ANL (i.e., ANL averaged across speech presentation levels) or ANL growth (i.e., the slope of the ANL function) varied between groups but did not show significant difference. The effect of presentation level with the speech fixed at different levels (50, 63, 75, or 88 dB A) on ANL in normal hearing and hearing impaired listeners was investigated (Recker and Edwards, 2013). Listeners were asked to adjust the level of the background noise to the maximum level at which they were willing to listen while following the speech, which was fixed at particular intensity. In second part of the same experiment, noise level was fixed at different levels (50, 60, 70, or 80 dB A). In this task listeners were made to adjust the level of the speech to the minimum, preferred, or maximum levels at which they were willing to listen to speech, at fixed level of noise. Results showed that varying presentation level either by fixed level of speech or noise did not show any change in the growth of ANL.

2.1.4. Gender

Female speakers were utilized to record speech passages in a study (Nabelek et al., 1991). Male and female participants were taken and ANL was estimated on them using recorded speech passage by female voice. Results revealed that there was no significant difference between male and female groups. The effect of gender on ANL utilizing male and female speech passages was assessed in a study (Rogers et al., 2003). A total of 25 participants in each gender group were considered in their study. The result suggests that though male group had obtained higher most comfortable level (MCL) and maximum acceptable background noise level (BNL) than female group, there was no significant difference in ANL. Further, there was no difference in ANL for speech passage produced by male and female speakers. It infers that scores of ANL is same for both male and female participants. In addition, irrespective of the speech produced by either male or female has no effect on ANL.

2.1.5. ANL and aided condition

The difference in ANL in aided and unaided conditions was investigated in a study (Agarwal and Manjula, 2008). Participants were adults having mild, moderately severe and severe SNHL; and mixed hearing loss. The results revealed that there was no difference between unaided and aided ANL among the participants. ANL was assessed in 39 individuals using hearing aids monaurally or binaurally (Freyaldenhoven et al., 2006). There was no change in the ANL in binaural condition when compared to monaural condition. In some of the participants, the monaural ANLs were better than the binaural condition. The possible contributions were inter-aural differences in the ANL leading to deterioration in the ANL. Hence, it was recommended to use monaural amplification in such participants. ANL was measured in 191 hearing aid users who were classified into three groups such as full time users, part time users and non-users (Nabelek et al., 2006). The results of regression analysis could predict the hearing aid use with 85% accuracy that is; those individuals who used hearing aid full time were able to accept more noise than their counterparts.

3. Prescription of hearing aid gain for older adults

It is well established that increasing gain helps in better speech recognition scores. However, at the same time circuitry noise from hearing aid will also increase which might hamper the speech perception in those individuals who are annoyed by noise. In addition, ambient noise in the environment is also amplified and reduces the SNR. The effect of hearing aid gain and SNR in the ear canal on the latency and amplitude of cortical auditory evoked potentials was studied (Billings et al., 2011). Nine normal hearing individuals were taken for the study. A 1 kHz tone was used in which intensity was varied in two conditions. In the first condition (unaided), the absolute intensity was varied from 40 to 70 dB in step of 10 dB step size. In another condition (aided), a 40 dB signal was delivered to a hearing aid to provide the same output of absolute intensity level. This was done by changing the gain from 0 dB to 40 dB in step size of 10 dB change in gain. They recorded evoked potential at cortical level and measured SPL generated in the ear canal. The result revealed that aided waveform at auditory cortex was reported to have reduced amplitude compared to unaided speech. This is attributed to the fact that some amount of circuitry noise from hearing aid is generated due to increase in gain. From analysing the recorded output of hearing aid at ear canal, it was noted that the noise level was increased linearly with increase in gain. These findings suggest that hearing aids modify signal-to-noise ratios of stimulus which is evident at cortical level. Therefore, it is important to adjust the hearing aid gain to an optimum level in order to maximize the signal-to-noise ratio. Thus, an additional care must be given during allocation of gain in hearing aids, especially to those who are annoyed by noise. This is because in older adults, the gain preferred may be different when compared to the gain prescribed according to the different fitting formulae.

3.1. Preferred and prescriptive gain

It was found that real ear insertion gain from prescriptive target always deviates from patient user gain at least in some frequencies. Standard deviation of 8 dB in user gain compared to prescriptive gain in individuals who had same hearing thresholds was reported in a study (Byrne and Tonisson, 1976). In another study, preferred insertion gain in naive and experienced hearing aid users was compared (Leijon et al., 1990). It was reported that the naive hearing aid users prefer to use lesser gain than experienced hearing aid users. In yet another study, preferred and target gain on 44 naive hearing aid users was compared and noted that three frequency average of preferred gain was less by approximately 1 dB when compared to target gain (Byrne and Cotton, 1988). Preferred user gain of 10–15 dB lesser than prescriptive gain provided by NAL formula was found in older adults (Leijon et al., 1984). They justified that their result of lesser gain preferred by user is because of binaural fitting. In extending their previous study by involving older adults who were fitted with hearing aid in one ear, they documented 5–6 dB less preferred gain than compared to a NAL prescriptive gain. The above studies suggest that preferred gain in older adults falls below prescriptive target. It might be speculated that prescribing gain in hearing aids according to the target gain of prescriptive formulae may result in increased annoyance due to noise. Thus, it is essential to quantify the annoyance level at the time of hearing evaluation and/or at pre-selection stage of hearing aid fitting.

4. Importance of ANL in adjusting gain

The measured amount of annoyance experienced by the individual can be used while adjusting gain in the hearing aids, in order to effectively reduce the discomfort due to noise. The effect of gain and digital noise reduction on hearing aid in low annoyance and high annoyance groups was studied (Navya and Hemanth, 2015). They classified the participants into low and high annoyance groups based on their ANL. The annoyance was measured at 3 conditions-prescriptive gain, −5 dB below the prescriptive gain and −3 dB below the prescriptive gain, respectively for both groups. Least annoyance was experienced at −5 dB below the prescriptive gain, followed by −3 dB below the prescriptive gain compared to prescriptive gain. But this effect was more evident in low annoyance group compared to the high annoyance group. Further, there was no significant difference in SNR-50 between the 3 conditions, for both the groups. Hence, annoyance was reduced for both the groups without compromising on the speech perception through the hearing aid.

5. To account annoyance level and speech perception in noise by activating and deactivating digital noise reduction and directionality in hearing aids

Majority of the patients complain poor speech in noise perception through the hearing aids. Aided SNR-50 may give better picture on outcome of the hearing in daily life situation. The SNR-50 is the signal-to-noise ratio required to obtain 50% of speech reception threshold. SNR-50 was measured in individuals with SNHL across different conditions (Boymans and Dreschler, 2000). Target speech stimulus was delivered from 0° azimuths and the noise was delivered from 90°, 180° and 270°. The performance was compared with the DNR on and off conditions with and without enabling the directional microphone in hearing aid. They found improvement of SNR-50 in activation of noise reduction but the significant difference was found by enabling the directional microphone with DNR ‘on’ condition than other experimental conditions. The effectiveness of noise reduction in a digital multichannel compression hearing aid was evaluated and eight experienced bilateral hearing aid wearers with moderate sensorineural hearing loss were included in the experiment (Alcantara et al., 2003). Two programs were enabled in the hearing aid. In one program DNR was activated and in another program DNR was deactivated. Participants were blinded regarding the program present in hearing aid. They were asked to regularly use each program for duration of three months period. Each participant was tested for speech recognition thresholds in different SNRs in 4 background noise (steady noise and noises with spectral or temporal dips) from both settings/programs in hearing aid. They found that speech recognition threshold was found to be better in DNR ‘on’ condition than compared to DNR ‘off’ condition. Modern hearing aids commonly employ digital noise reduction (DNR) algorithms and this has provided improved speech understanding in noise. In addition, apart from better improvement of speech in noise, different processing strategies in hearing aid also offered relaxed listening or increased ease of listening. The effect of digital noise reduction (DNR) on ANL was assessed in a study (Mueller et al., 2006). Twenty two adults fitted with 16 channel wide dynamic range compression hearing aid were considered for the study. All the hearing aids had DNR having modulation based on wiener filter type of DNR algorithms. The ANL was assessed in DNR-on and DNR-off condition. The results showed a significant reduction in ANL (4.2 dB) in DNR-on condition compared to DNR-off condition. Another study involved individuals who had different types and degrees of hearing loss, and the effect of DNR on ANL was studied (Agarwal and Manjula, 2008). The performance of individuals with moderate to severe degree of SNHL or mixed hearing loss was compared between the aided condition with DNR ‘off’ and DNR ‘on’. There was a significant improvement in ANL in the DNR ‘on’ condition. Further, activating the DNR and also enabling the option of directional microphone improves the signal level. In this processing strategy, accumulated noise level in amplified speech is reduced. To support the above notion a study was conducted to investigate the combined effect of DNR and directional microphone on acceptable noise level (Wu and Stangl, 2013). Twenty five adults with sensorineural hearing loss participated in the study. They found that with deactivating the DNR, the ANL was increased by 1.5 dB, whereas activating the DNR, ANL reduced by 2.8 dB. In addition, activating DNR and enabling option of directional microphone reduced the ANL by 2.8 dB. They concluded, when the hearing aid was switched from linear to WDRC mode, listeners perceived a noisier sound image, whereas activating the DNR with directional microphone reduced perceived noisiness. It was found that annoyance was reduced significantly in DNR-OFF condition when compared to the DNR-ON condition for both low and high annoyance groups (Navya and Hemanth, 2015). In addition, the annoyance rate was reduced as a function of reduction in gain accompanied with activation of DNR, in both groups.

6. Conclusion

In older adults the rejection of hearing aid (23.5%) is likely due to annoyance experienced by background noise. Adjusting gain and signal enhancement strategies in hearing aid (DNR and directionality microphone) reduces the annoyance level in individuals who are less able to put up with background noise. Thus, it is prerequisite to know the ANL at the pre-selection stage of hearing aid fitting so that rejection rates can be reduced.

Conflicts of interest

None.

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