J Am Acad Audiol 19:147–157 (2008)

Effects of Expansion Algorithms on Speech Reception Thresholds

DOI: 10.3766/jaaa.19.2.5

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Abstract

Expansion is commonly used to reduce microphone noise and low-level environmental noises that can be annoying to hearing aid users. It may also improve or reduce the perception of low-level speech. This study assessed the impact of two expansion algorithms, single and multiple channel, on speech reception thresholds (SRT) with 10 hearing impaired listeners wearing hearing aids with ADRO® processing. The single-channel algorithm suppressed sounds below 45 dB A, while the multiple-channel algorithm suppressed sounds below the long-term average spectrum of speech at either 55 or 45 dB SPL. The mean HINT SRTs in quiet were 39.4, 40.7, 40.6, and 41.8 dB A without expansion, with single-channel expansion, and with multiple-channel expansion at expansion thresholds of 45 and 55 dB SPL, respectively. The difference in mean SRT was only statistically significant between no expansion and multiple-channel expansion at a 55 dB SPL threshold. A regression analysis between the change in individual SRT for each expansion condition and pure tone average hearing loss showed no correlation. Our calculations indicate that only those with exceptionally good hearing will find microphone noise audible. The current practice of prescribing expansion algorithms based on hearing thresholds alone is questioned, and other rationales are discussed.

Key Words: Adaptive dynamic range optimization, expansion, internal noise

Abbreviations: ET = expansion threshold; HINT = *Hearing In Noise Test*; MCNS = multiple-channel noise suppression; PTA = pure tone average; SCNS = single-channel noise suppression; SRT = speech reception threshold

Sumario

La expansión se utiliza comúnmente para reducir el ruido de los micrófonos y los ruidos ambientales de bajo nivel que pueden ser perturbadores para los usuarios de auxiliares auditivos. También puede mejorar o reducir la percepción de lenguaje a bajo voumen. Este estudio evaluó el impacto de dos algoritmos de expansión, de canal múltiple y el canal único, sobre los umbrales de recepción del lenguaje (SRT) con 10 sujetos hipoacúsicos utilizando auxiliares auditivos con procesamiento ADRO®. El algoritmo de canal único suprimió sonidos por debajo de 45 dB A, mientras que el algoritmo de canal múltiple suprimió sonidos por debajo del espectro promedio a largo plazo del lenguaje, a 55 ó 45 dB SPL, respectivamente. La diferencia en el SRT medio fue sólo estadísticamente significativa entre la no expansión y la expansión de canal múltiple a un umbral de 55 dB SPL. Un análisis de regresión no mostró correlación entre el cambio en los SRT individuales para cada condición de expansión y la pérdida auditiva promedio para tonos puros. Nuestros cálculos indican que solamente aquellos con una audición excepcionalmente buena encontrarán audible el ruido del micrófono. Se cuestiona la práctica actual de prescribir algoritmos de expansión con base sólo en umbrales auditivos, y se discuten otros razonamientos.

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Palabras Clave: Optimización del rango dinámico adaptativo, expansión, ruido interno

Abreviaturas: ET = umbral de expansión; HINT = Prueba de Audición en Ruido; MCNS = supresión de ruido de canales múltiples; PTA = promedio tonal puro; SCNS = supresión de ruido de canal único; SRT = umbral de recepción del lenguaje

The clinical goal of expansion in hearing aids is to suppress or reduce low-level noise without introducing perceptual artifacts and without adversely affecting the perception of speech at low input levels. This study compared the effects of two alternative expansion schemes on speech reception thresholds. A previous study (Zakis and Wise, 2007) showed that both schemes were effective at reducing low-level noise and that the multiple-channel expansion scheme introduced fewer artifacts than the single-channel scheme. Together, this study and the previous one investigated whether these two schemes achieved these clinical goals. This study also proposes alternative rationales for the use of expansion with individual listeners.

Essentially, expansion is the opposite of compression in that gain is reduced as the input level falls below the expansion threshold. Expansion is commonly used in hearing aids with wide dynamic range compression (WDRC) to prevent the overamplification of low-intensity sounds such as internal circuit noise and low-level environmental sounds. The overamplification of these sounds may be annoying to hearing aid users (Venema, 2000; Bray and Ghent, 2001) and could possibly mask soft speech (Agnew, 1996). The dominant internal noise source in current hearing aids is from the microphone and is reported to be equivalent to an input signal of about 20–25 dB SPL (Holube and Velde, 2000; Kuk, 2002), which is then amplified by the amount of gain prescribed for the hearing loss. By reducing the gain of the hearing aid for low input levels, expansion suppresses the level of the noise at the output of the hearing aid and theoretically could improve speech intelligibility at soft input levels. Dillon et al (2003) asked 10 hearing impaired participants to compare five behind-the-ear aids from different manufacturers in a quiet room and found that participants preferred devices with lower internal noise levels. Several studies have shown that listeners prefer the use of an expansion algorithm in quiet and low-level noise over no expansion activated (Bray and Ghent, 2001; Plyler et al, 2005a, 2006b, 2007). However, a reduction, rather than an improvement, in speech intelligibility may actually be the trade off (Bray and Ghent, 2001; Plyler et al, 2005a, 2006b, 2007).

Single-channel expansion algorithms typically apply the same gain reduction across all frequencies. When the input level falls below the expansion threshold, the algorithm is activated and less gain is applied than if the signal was at or above the threshold. Evaluation of single-channel expansion algorithms is limited. Plyler et al (2005a) evaluated a single-channel expansion algorithm with an expansion threshold of 50 dB SPL, an expansion ratio of 1:2, and attack and release times of 512 msec. Twenty participants were divided into two hearing loss groups (two adjacent low-frequency thresholds better or poorer than 40 dB HL). They found that 85% of participants preferred the use of an expansion algorithm over no expansion activated in quiet environments. However, speech intelligibility at levels of 40 and 50 dB SPL was significantly reduced with expansion activated in quiet using the Connected Speech Test (CST), while the intelligibility of speech at 60 dB SPL was not affected. Speech intelligibility testing in noise using the *Hearing in Noise Test* (HINT) showed similar results, with significant deterioration at speech levels of 40 and 50 dB SPL, but intelligibility of speech at 60 dB SPL was not affected by the activation of the expansion algorithm. The effects of different time constants in a single-channel expansion system were also evaluated by Plyler et al (2005b, 2006a). With an expansion threshold of 50 dB SPL and an expansion ratio of 0.5:1, the time constants were varied in each program for comparison. Equal attack and release times of 128, 512, 2094, and 4096 msec were used, and the results showed 16 out of 30 participants had a preferred time constant. Of these 16 participants, 75% preferred 128 msec. Speech testing in quiet and noise showed the intelligibility of speech at 65 dB SPL decreased as the time constants were lengthened.

Multiple-channel expansion algorithms may have individual expansion thresholds, ratios, and time constants for each frequency channel. This allows the possibility of shaping the expansion parameters around soft speech and may preserve more of the speech signal than with a single-channel expansion algorithm. Bray and Ghent (2001) did performance-intensity functions using isophonemic words on 17 participants with and without multiple-channel expansion. While the expansion threshold, expansion ratio, and time constants were not stated, speech results showed a reduction in intelligibility of speech presented at 20 dB HL (approximately 40 dB SPL) when expansion was activated. The average percent correct scores at this level decreased from 20 to 10%. Speech at presentation levels of 35, 50, 65, and 85 dB HL showed no significant change in scores between the expansion-on and expansion-off conditions. Plyler et al (2006b, 2007) evaluated a four-channel expansion algorithm in the Starkey Axent II using three memories, each activating a different expansion setting. One memory had no expansion activated, one had expansion activated in the two channels below 2000 Hz and no expansion in the two channels above 2000 Hz, and another memory had expansion activated in all four channels. An expansion threshold of 50 dB was used for the lowest two channels, and 30 dB was used for the highest two channels. An expansion ratio of 0.5:1 and a time constant of 512 msec were used in all memories. Speech testing showed a statistically significant decrease in CST scores in quiet and an increase in HINT speech reception thresholds (SRTs) in noise for speech levels at 40 and 50 dB SPL, but not 60 dB SPL, for both expansion-on conditions. The subjective evaluation indicated that participants significantly preferred the use of either form of expansion over having no expansion activated in their real-world experiences.

Recommendations on the use of an expansion algorithm have traditionally been based on hearing thresholds, and expansion is typically recommended for WDRC users with near normal hearing thresholds (Venema, 2000). Agnew (1996, 1997) performed two experiments in which he asked listeners to increase the level of internal circuit noise until they found it "audible" and then "objectionable." The results of both studies indicate that most listeners reported internal circuit noise as being audible when the noise level reached their best threshold of hearing sensitivity. As a coarse generalization, hearing aids with inherent noise output levels of about 45–50 dB SPL will start to become audible to subjects with mild to moderate sloping sensorineural hearing loss (Agnew, 1996). At about 8–10 dB above those levels, some listeners will find the internal circuit noise objectionable (Agnew, 1996). Some hearing aid fitting software automatically selects expansion settings based on the audiogram entered. Holube and Velde (2000) recommend using an expansion threshold of 30 dB SPL to effectively reduce the microphone noise to a level below the listener's hearing thresholds. However, output level measurements of the hum of a computer and refrigerator from Bray and Ghent (2001) indicate this threshold is unlikely to be high enough to reduce low-level environmental sounds.

Plyler et al (2005a) suggest listeners with moderate degrees of hearing loss are also more satisfied with their hearing aids when expansion is activated and prefer the use of expansion in quiet environments over having no expansion activated. They also suggest that speech intelligibility reductions with expansion activated were comparable for all degrees of hearing loss used in the trial, indicating that there is no correlation between the effects of single-channel expansion on soft speech and the degree of hearing loss. Nevertheless, it was also reported that larger increases in satisfaction and stronger preferences for expansion were noted by listeners with less hearing impairment than those with more hearing impairment in low-level noise environments.

The studies described above have assessed the impact of expansion algorithms on speech at various fixed levels. This research focuses on the application of single- and multiple-channel expansion algorithms to suppress the internal microphone noise of the hearing aid and the impact on speech reception thresholds in quiet environments. Speech reception thresholds were thought to be more sensitive to the effects of expansion algorithms than measurements at fixed speech levels. The goal of both expansion algorithms used in this study was to suppress internal microphone noise while maintaining the intelligibility of speech at 55 dB SPL. Therefore, these expansion algorithms have the potential to lower speech reception thresholds, and this effect was investigated in this study at an individual level. The relationship between the degree of hearing loss and the effect of expansion on individual speech reception thresholds was also examined. The results are used to discuss rationales for prescribing expansion algorithms as well as areas for future research. For the purposes of this paper, the term *noise suppression* is used to indicate the application of expansion to suppress internal circuit noise.

METHODS

Participants

Ten adults, 64 to 85 years of age, with symmetrical, sensorineural hearing loss participated in this study. All participants except for one were previously hearing aid wearers (seven used WDRC aids and two used ADRO aids, which will be described in the following section). The mean audiogram is shown in Figure 1 with pure-tone average thresholds (500, 1000, and 2000 Hz) ranging from 25 to 75 dB HL.

Hearing Instruments

Every participant was fit binaurally with Interton Bionic-Big Nano behind-the-ear hearing aids, which used the 32-channel version of the ADRO amplification algorithm (Blamey, 2005). ADRO (adaptive dynamic range optimization) can be considered to be an adaptively optimized linear amplifier. When listening to speech at low input levels in quiet, ADRO will be operating at its maximum gain setting. The time constants for ADRO, which typically changes gain at a maximum rate of 3 dB/sec, are much longer than the time constants for the noise suppression algorithms, and thus ADRO may be thought of as a linear amplifier for the purpose of this study.

Hard acrylic, carved shell earmolds with 2 mm vents were used for nine participants, while one participant wore audisil, carved shell earmolds with 2 mm vents. The hearing aids were programmed with ADRO output fitting predictions derived from the participants' audiograms. These fitting predictions were based on a linear regression analysis of 176 ADRO fittings from previous studies (Blamey, 2005). Each aid was calibrated and verified to give outputs within 3 dB of the programmed fitting at frequencies from 250 Hz to 5 kHz in a 2-cc coupler.

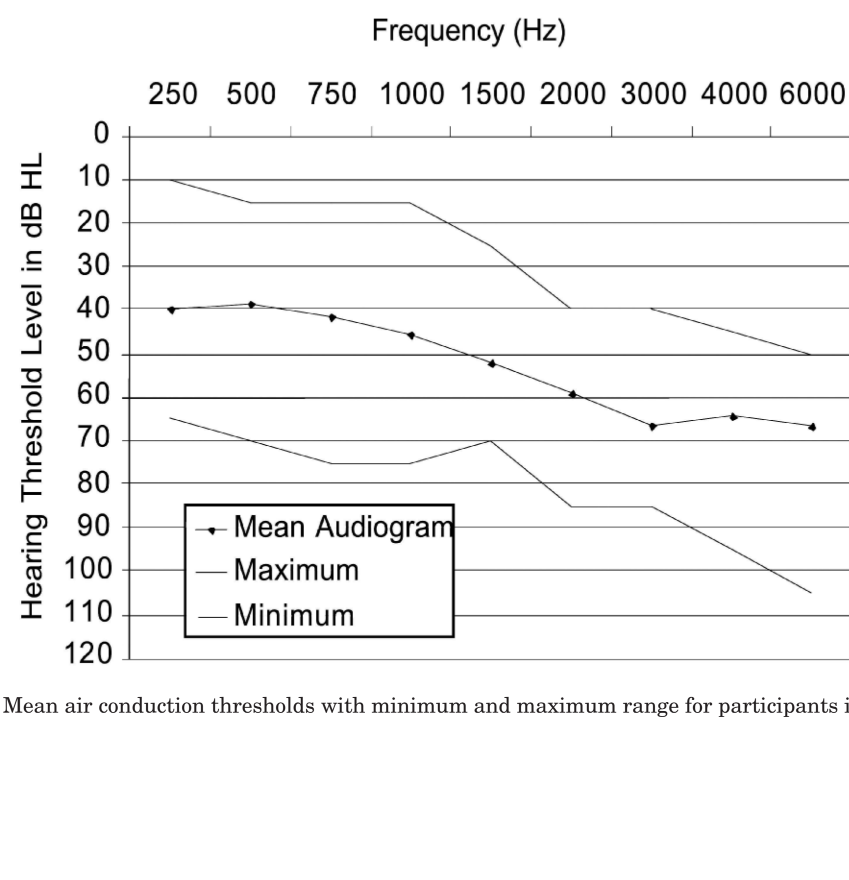

Figure 1. Mean air conduction thresholds with minimum and maximum range for participants in this trial.

Participants wore the hearing aids for one week to acclimatize to the algorithm. During the acclimatization period, the first memory had an adaptive directional microphone and multiple-channel noise suppression with a wideband expansion threshold (ET) of 55 dB SPL (described in subsequent paragraphs). The rationale for using this noise suppression setting was evaluation in listeners' own environments as it was a newly developed algorithm. The second memory used a telecoil input. The volume control was disabled for all participants.

For speech reception threshold testing, the same two Interton Bionic-Big Nano hearing aids were used for every participant, programmed to the fitting used in the acclimatization period. An omnidirectional microphone was activated, and all other features were turned off except for the various noise suppression algorithms used for comparison. The output of this pair of aids was measured to ensure activation of the noise suppression algorithm. Each memory was identical except for the type of noise suppression used for each condition. One memory was programmed with no noise suppression algorithm active (OFF); a second memory had multiple-channel noise suppression with a 45 dB SPL wideband ET (MCNS 45); and a third memory had multiple-channel noise suppression with a 55 dB SPL wideband ET (MCNS 55); and a fourth memory had single-channel noise suppression with an ET of 45 dB A (SCNS). These memories were randomized and counterbalanced across participants.

The single-channel noise suppression algorithm used an A-weighted version of the input signal to calculate the noise suppression gain reduction (Fiket et al, 2005). The parameters used were an expansion ratio of 0.7:1, an expansion onset time constant of 200 msec (falling input level), an expansion offset time constant of 20 msec (rising input level), and an ET of 45 dB A.

The details of the MCNS algorithm used in this evaluation are described in Zakis and Wise (2007). The algorithm used nine noise suppression channels spread across the 6 kHz bandwidth of the aid, with the ET in each channel based on the long-term average speech spectrum for "casual" speech as measured by Pearsons et al (1977). For convenience, a wideband threshold was used to control the default thresholds within each of the nine channels. In this study, 45 and 55 dB SPL wideband ETs were assessed. A wideband ET of 55 dB SPL means that the ET for each noise suppression channel was set to the long-term average speech level in the channel for speech presented at the "casual" level of 55 dB SPL. For the wideband ET of 45 dB SPL, the threshold for each channel was reduced by 10 dB. The expansion onset time constant (for a falling input level) was 200 msec, the expansion offset time constant (for a rising input level) was 20 msec, and the expansion ratio was 0.7:1. An expansion ratio of 0.7:1 was the recommended setting for this algorithm to sufficiently reduce internal noise while maintaining sound quality (Zakis and Wise, 2007).

HINT Testing

The HINT (Nilsson et al, 1994) was used for measuring speech reception thresholds (SRT). Speech reception thresholds were thought to be more sensitive to the effects of expansion and the masking of speech by microphone noise than speech tests at higher fixed levels. Testing was done in quiet conditions only, and the level of the speech was adapted for 20 sentences per list to find the 50% correct level. The first four sentences of each list were adapted in 4 dB steps, while the remaining sentences used a 2 dB step size. The output levels of the HINT were calibrated at the position of the participant's head and checked throughout the study.

Participants were seated one meter from a loudspeaker located at 0^o azimuth in a sound-treated booth. One HINT practice list was administered to the participant before testing began. Two lists per noise suppression condition (OFF, MCNS 55, MCNS 45, and SCNS) were performed for each participant. The results were averaged for a mean SRT per noise suppression condition. These lists were automatically randomized by the HINT system across participants.

Noise Measurements

First, the microphone noise was measured for the Interton Bionic-Big Nano. A B&K sound level meter was used to measure the one-third octave output of the aid in a 2-cc coupler using 35 dB of real ear insertion gain for the average adult ear. This amount of real ear insertion gain ensured that the amplified microphone noise dominated the output circuit noise in the 2-cc coupler. The 2-cc coupler gain values were subtracted from the measured output level to get the one-third octave equivalent input noise for the hearing aid. Two methods were used to estimate whether or not the participants in the trial could hear the microphone noise of the hearing aid.

In the first method, ADRO maximum gain values were added to the equivalent input noise to estimate the one-third octave microphone noise level at each frequency in a 2-cc coupler for each participant. This was done for each noise suppression condition and plotted on a graph with each participant's audiometric thresholds in 2-cc dB SPL. If the amplified microphone noise level was greater than or equal to the hearing threshold level in any band, it was assumed the listener would hear the microphone noise of the hearing aid (Agnew, 1996, 1997).

In the second method, Moore and Glasberg's (1997) model of loudness perception for cochlear hearing loss was used to estimate whether or not the participants in this trial could theoretically hear the microphone noise. This model estimates excitation patterns that sound will produce, taking into account the outer and middle ear transfer function, and converts results to perceived loudness in phons. Version 3.2 of the model was downloaded from the Cambridge University Web site and used to calculate the perceived loudness of the amplified microphone noise for each subject. To predict binaural loudness with the model, air conduction thresholds and ADRO maximum gains were averaged between the right and left ears. The ADRO maximum gains were added to the one-third octave equivalent input noise levels, converted from 2-cc units to free-field dB SPL with conversion data from column G of table 1 of Bentler and Pavlovic (1989), and the result entered into the model to calculate loudness perception for each participant. The proportion of hearing loss due to outer hair cell damage was left at the default of 80% initially, and then all data were recalculated assuming 100% of the total being from outer hair cell damage within the default constraints of up to 55 dB for frequencies below 2 kHz and up to 65 dB for frequencies at or above 2 kHz.

RESULTS

HINT Testing

Figure 2 shows SRT results for each condition plotted against the pure tone average thresholds (PTA) of each participant. As expected, SRT increased with increasing

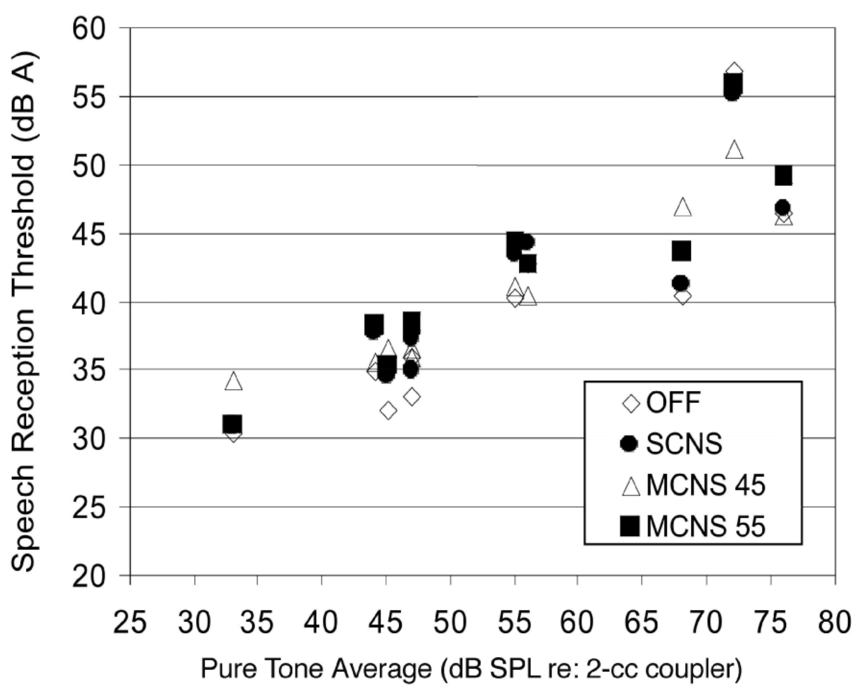

Figure 2. Aided speech reception thresholds, measured using the HINT in quiet, as a function of pure tone average hearing loss (500, 1000, 2000 Hz) in dB SPL (re: 2-cc coupler) for each participant.

PTA. All SRT values were below the ET except for the three subjects with the greatest PTA. SRT and PTA were significantly correlated (r = .87, .87, .95, and .92 ; $p<.001$; for noise suppression conditions of OFF, SCNS, MCNS 45, and MCNS 55, respectively). Speech reception thresholds were typically lower than the individual's PTA value.

The average SRT was 39.4, 40.7, 40.6, and 41.8 dB A for noise suppression conditions of OFF, SCNS, MCNS 45, and MCNS 55, respectively. A repeated-measures ANOVA showed that the differences in mean SRTs were statistically significant (F = 3.12, df = 3, 27, $p < 0.05$). Post hoc pairwise comparisons using the Bonferroni procedure showed the only significant difference was between MCNS 55 and the OFF condition (t = 3.057, df = 10, $p < 0.05$), and this finding was confirmed with a paired-comparison t-test (t = 4.04, df = 10, $p < 0.01$). These results indicate that MCNS 55 was the only condition that had a statistically significant effect on speech reception thresholds in quiet, although most mean SRT values were below the ET used in the experiments.

The change in SRT from the OFF condition to each of the three conditions with a noise suppression algorithm active is shown in Figure 3, plotted against the PTA hearing loss for each participant. A regression analysis was performed to determine if the change in SRT was related to the degree of hearing loss and no significant correlations were found ($p>.05$) for any of the three noise suppression conditions. This indicates that the effects of noise suppression on aided SRT are not strongly dependent on hearing thresholds when the ADRO amplification scheme is used.

Internal Noise Measurements

Only one participant had hearing thresholds low enough to possibly hear the internal noise of the hearing aid. Figure 4 shows the calculated microphone noise at ADRO maximum gain for OFF and each noise suppression condition, as well as hearing thresholds converted to 2-cc coupler units (dB SPL) for participant 5 from the trial. Based on these measurements, this participant may have heard the microphone noise when noise suppression was not activated. With any of the noise suppression algorithms enabled, the microphone noise fell below the hearing thresholds of this participant at all frequencies, as shown in Figure 4. For the remaining participants, the amplified microphone noise was below their hearing thresholds at all audiometric frequencies, which suggests that the microphone noise would have been inaudible without noise

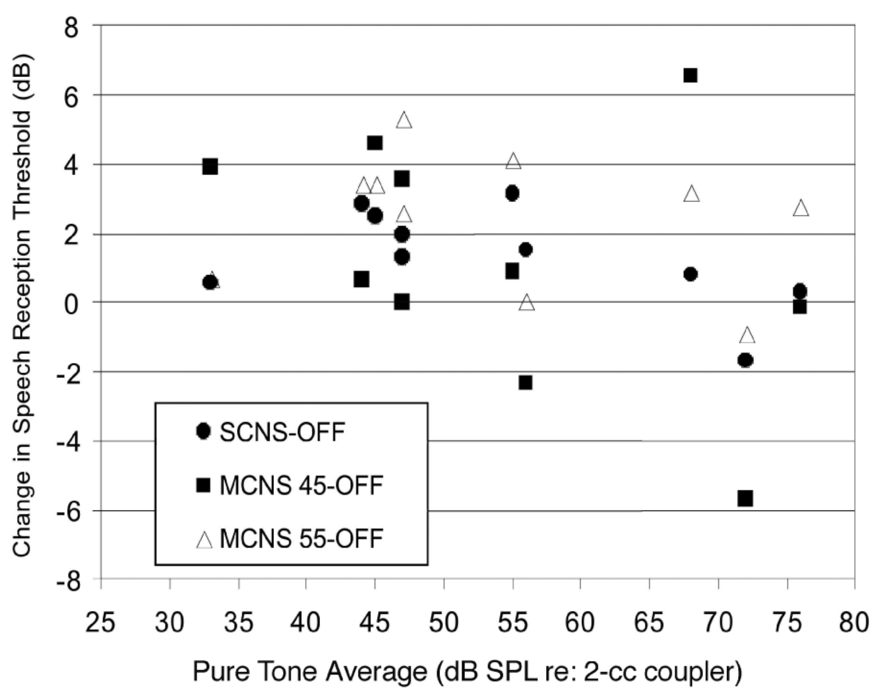

Figure 3. Change in speech reception thresholds for each expansion condition when compared to the expansion OFF condition. A value of 0 dB shows that the SRT with expansion on was the same as the SRT for expansion OFF, while negative values show a reduction in the SRT in quiet (better performance) with expansion activated. The pure tone average was calculated using thresholds at 500, 1000, and 2000 Hz.

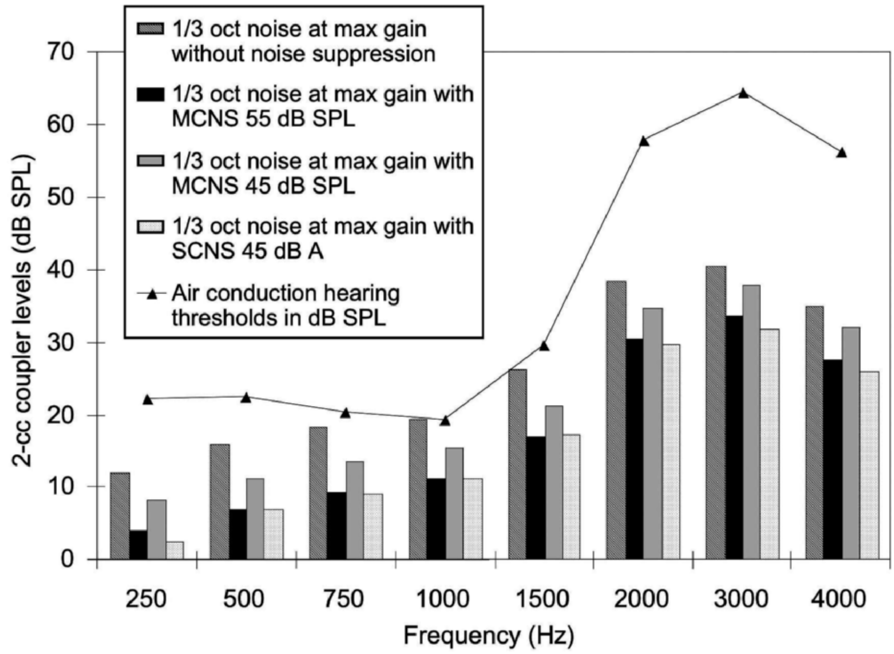

Figure 4. Microphone noise levels at the output of the aid with expansion OFF, SCNS, MCNS 45, and MCNS 55, and right ear air conduction thresholds (triangles) for participant 5.

suppression activated.

Moore and Glasberg's (1997) model of perceived loudness verified these results. Without noise suppression activated, only participant 5 was estimated to be able to hear the microphone noise of the hearing aid at a loudness of 4.9 phons. With any of the three algorithms enabled, the loudness model estimated the microphone noise to be inaudible to this participant. The results were identical for both the 80 and 100% estimates of the total hearing loss being due to outer hair cell dysfunction.

DISCUSSION

The primary purpose of this study was to investigate the effects of expansion algorithms on the SRT. Two possible factors may influence SRT in quiet: audibility of the speech signal and masking of the speech signal by microphone noise. If the SRT is below the ET, the gain applied to the speech signal with noise suppression active will be less than the gain applied without noise suppression, and consequently the SRT will be raised a little. This was observed in this study. This result is consistent with the reduction of speech intelligibility at low levels observed in previous studies (Bray and Ghent, 2001; Plyler et al, 2005a, 2006b, 2007). While the milder expansion ratio used in this study may account for the smaller reduction in speech intelligibility that we found over previous studies, different time constants and sound processing algorithms mean direct comparisons cannot be made. The goal of the noise suppression algorithms evaluated in this study was to reduce the level of internal noise while maintaining the intelligibility of speech at 55 dB SPL. It was confirmed that this goal was met in Zakis and Wise (2007). Theoretically, internal noise suppression may improve speech intelligibility by reducing the masking of speech by the noise. This effect has not been reported in the literature and was not observed in this study. This is possibly because the noise was likely to be inaudible to most participants and therefore had no masking effect, and the mean SRTs without noise suppression were well above typical microphone noise levels.

HINT testing resulted in an average SRT of 39.4 dB A without noise suppression. The average SRT was 1.3, 1.2, and 2.4 dB greater for the SCNS 45, MCNS 45, and MCNS 55 conditions, respectively. While the SRT for MCNS 55 was statistically different from the SRT for the OFF condition, this difference is not likely to be clinically significant because the SRT values were lower than the casual speech levels that are expected to occur in real-world environments (Pearsons et al, 1977). This suggests that activation of these noise suppression algorithms will have a minimal effect on speech intelligibility in real-world environments.

For the condition with a statistically significant result, the mean change in SRT was as expected. The mean SRT in the OFF condition was 15.6 dB below the 55 dB SPL threshold for MCNS 55. Peak levels in the speech signal will control the operation of the MCNS algorithm due to the asymmetric time constants that were used. Speech peaks are approximately 10 dB higher than RMS levels (Byrne et al, 1994), and the HINT uses the RMS level to characterize the SRT. It was expected that MCNS 55 with an expansion ratio of 0.7:1 would lower the gain for the speech by about 2.4 dB (5.6 dB - [5.6 dB/0.7]). The measured change in the mean SRT from the OFF condition to MCNS 55 was 2.4 dB, as expected.

The second purpose of the study was to find out if the changes in SRT could be predicted by the degree of hearing loss. Individual SRT values were compared to PTA hearing loss, and as expected, a significant correlation was found. However, the regression analysis showed the change to SRT when activating a noise suppression algorithm was not related to hearing thresholds. This result is in agreement with Plyler et al (2005a), who found that the effects of a single-channel expansion algorithm on speech in quiet and in noise were not related to the degree of hearing loss, and the current study has shown that this also applies to MCNS. However, the present data are not particularly sensitive to this effect because of the very small differences in SRT that were observed. Future studies may include more participants with a wider range of hearing loss to increase sensitivity.

Microphone noise level calculations and the loudness perception model both suggest that only one participant had thresholds mild enough to hear the microphone noise in the OFF condition. This led us to question microphone noise reduction as a rationale for expansion. Our calculations indicate that only listeners with quite good hearing would benefit from the use of expansion for this purpose. With the increase in "open ear" hearing aids, more people with normal and mild thresholds, who would be excellent candidates for using an expansion algorithm to reduce microphone noise, will be using hearing aids. Figure 5 shows approximate microphone noise levels from a range of Knowles microphones, based on equivalent input noise data shown on their specification sheets. The levels shown in Figure 5 are for 0 dB 2-cc coupler gain. By adding the listener's prescribed hearing aid 2-cc coupler gain to these microphone noise levels and comparing the result to the listener's hearing thresholds

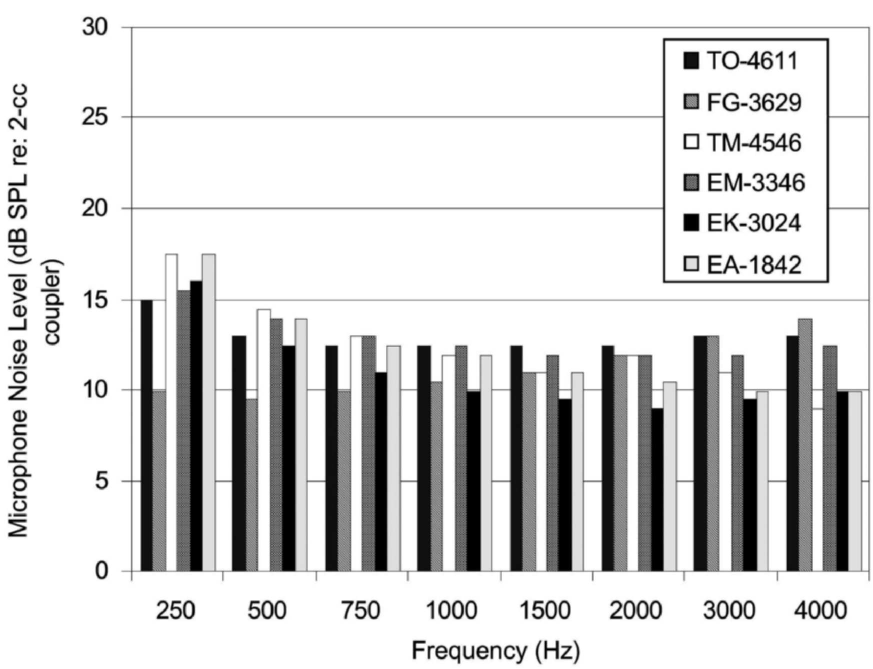

Figure 5. Approximate microphone noise levels of various Knowles microphones as taken from their datasheets.

in dB SPL, candidacy for the use of expansion to reduce microphone noise can be determined. The noise levels for the microphones are similar at most frequencies, and since Knowles microphones are widely used in the hearing aid industry, these levels are applicable for a wide range of hearing aids.

Another possible benefit of expansion is for reducing environmental noise in quiet and low-level conditions. In low-level conditions, Plyler et al (2005a) suggest those with better hearing thresholds were more likely to prefer the use of an expansion algorithm over those with poorer hearing thresholds. However, they also conclude that 85% of their participants with varying degrees of hearing loss preferred the use of expansion in quiet environments over no expansion. These participants also gave significantly higher satisfaction ratings when using expansion in quiet environments, despite any speech intelligibility reduction expansion may have caused. Considering the possible subjective benefits of expansion for a variety of degrees of hearing loss, and that any effects on speech recognition are not related to the degree of hearing loss, we should further investigate prescribing expansion algorithms based on tolerance of environmental noises in quiet and low-level conditions rather than on hearing thresholds alone as is commonly done.

One clinical procedure, the acceptable noise level, measures the maximum level of background noise acceptable to the listener while listening to speech at the listener's most comfortable level (Nabelek et al, 1991). Typically, acceptable noise levels are measured using louder noise levels than an expansion algorithm would influence while listening to speech at the listener's most comfortable loudness level. Research has shown that the acceptable noise level provides a good indication of hearing aid use (Nabelek et al, 2006). A modified version of the acceptable noise level procedure could include measuring tolerance of a variety of low-level environmental sounds with and without expansion activated while listening to soft levels of speech.

The current study has shown that these noise suppression algorithms can have minimal impact on SRT as measured using the HINT in quiet conditions. These changes to SRT are not correlated to PTA hearing loss. The application of expansion algorithms for microphone noise reduction in hearing aids may only be beneficial to those with normal or very mild hearing thresholds. However, the use of expansion for other benefits, including reduction of low-level environmental noise, may be applicable to a variety of degrees of hearing loss and should be further investigated. Prescribing expansion algorithms based on tolerance of low-level environmental noise rather than audiometric thresholds is also an area for further research.

CONCLUSION

In conclusion, these results suggest that using expansion for the purpose of microphone noise reduction is useful only for people with normal or very mild hearing thresholds, such as in the case of open-ear fittings, and expansion algorithms can have minimal impact on speech reception thresholds in quiet. The small changes in speech reception thresholds are not correlated to pure tone average hearing loss. Other beneficial uses of expansion, such as reduction of low-level environmental noise, have been suggested in the literature. Fitting expansion algorithms based on tolerance of low-level environmental noises rather than on hearing thresholds is an area for future research.

Acknowledgments. The authors would like to thank and acknowledge Peter Blamey, Bernadette Fulton, and Jutta Hau for their helpful advice, and Brenton Steele for designing the single-channel expansion algorithm. The study was approved by the Human Research and Ethics Committee of the Royal Victorian Eye and Ear Hospital under Project 03/529H.

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