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Noise Reduction Strategies for Elderly, Hearing-Impaired Listeners

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Abstract

A variety of technical features are available in hearing aids in order to reduce the negative effects of background noise. In this investigation, 16 elderly sensorineurally hearing-impaired hearing aid candidates provided word recognition responses while listening through simple linear amplification and through a hearing aid featuring one of the following: (1) high-frequency emphasis amplification, (2) a directional microphone, (3) automatic signal processing (ASP) circuitry, and (4) ZETA noise reduction circuitry. The subjects provided responses to monosyllabic words presented in a background of cafeteria noise. Results indicated that all four noise reduction techniques provided a similar magnitude of benefit over linear amplification. In a follow-up investigation, five of the original 16 subjects were recalled in order to listen through either simple linear amplification or through the ZETA circuitry with and without the benefit of visual and contextual cues. The subjects repeated sentences presented in a background of cafeteria noise. Without the benefit of the supplemental cues, the ZETA aid allowed for superior performance when compared to the linear aid. When the visual and contextual cues were available, the ZETA aid continued to provide a performance advantage over linear amplification.

Key Words: Linear amplification, ZETA aid, hearing aids, hearing disorders, aged

Controlling the deleterious effects of back-ground noise has long been a design goal in the development of hearing aid technology. Two specific noise control techniques, high-pass amplification and directional microphones, have been available for several years. Over the past few years, other technologies have been introduced into the commercial hearing aid market, including automatic signal processing (ASP) circuitry* and ZETA circuitry. Although this list of four noise reduction techniques is not exhaustive, it does include four of the more popular approaches to controlling background noise.

Although reports are available in the literature concerning the performance of each one of these noise reduction technologies compared to linear amplification (Gordon-Salant, 1984; Hawkins and Yacullo, 1984; Klein, 1989; Sigelman and Preves, 1987; Stach et al, 1987; Stein and Dempesy-Hart, 1984; Van Tasell et al, 1988; Wolinsky, 1986) there is little information available concerning the relative performance of these devices in the same group of listeners. Further, the studies that have been reported concerning the effectiveness of noise-reduction technologies have used either only non-elderly subjects (Klein, 1989; Van Tasell et al, 1988), an undifferentiated group of elderly and non-elderly subjects (Gordon-Salant, 1984; Hawkins and Yacullo, 1984; Stach et al, 1987; Stein and Dempesy-Hart, 1984; Wolinsky, 1986), or a group of subjects with no ages reported (Sigelman and Preves, 1987). Since most hearing aid users are elderly, it is important that the effectiveness of any new device be demonstrated for these most likely users.

Therefore, the purposes of this investigation were threefold: (1) to compare the effects on word recognition in noise of two traditional noise reduction techniques (high-frequency emphasis amplification and directional microphones) and two recently introduced techniques (ASP cir-

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cuitry and ZETA circuitry), (2) to make these comparisons within a group of elderly, hearing-impaired listeners, and (3) to determine whether the benefit provided by noise-reduction circuitry is redundant or nonredundant to the benefit provided by extra-auditory cues (visual and contextual information).

EXPERIMENT I

Method

Subjects

Sixteen elderly subjects with symmetrical sensorineural hearing loss participated. The age range was from 60 to 77 years, with a mean of 70 years. Twelve subjects were not hearing aid users. One subject was a current monaural user and four subjects were current binaural users. Figure 1 provides the mean and range of audiometric thresholds across frequency for the subject group. These thresholds represent one test ear from each subject. The choice of test ear for each subject will be explained below. All losses were sensorineural, with all audiometric, tympanometric, and history information being negative for middle ear or retrocochlear involvement.

Materials

The subjects provided responses to tape-recorded items from the CID W22 monosyllabic word lists. These materials were presented in a background of cafeteria noise. The speech material was presented in the soundfield at 0 degrees azimuth, with the cafeteria noise presented in the soundfield at 180 degrees azimuth.

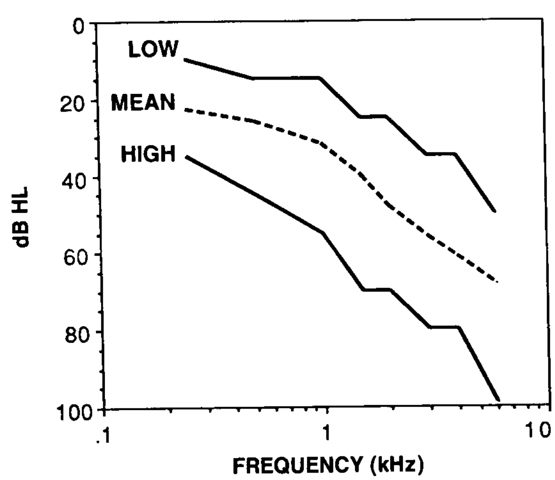

Figure 1 Mean and range audiogram of the 16 test ears from the subject population.

Hearing Aids

Five aided conditions were included in this investigation: (1) linear: A Phonic Ear 805CD2 BTE hearing aid was used in its widest frequency response setting, providing broadband, linear amplification. (2) high-pass: The Phonic Ear 805CD2 was set to the most extreme low-cut tone-control position, providing high-frequency emphasis amplification. (3) directional: The adjustable directional/omnidirectional microphone on the Phonic Ear aid was set to the directional position. The aid was set to the broadest frequency response. (4) ASP: A Bosch Star 33PP-ANR BTE hearing aid with automatic low-frequency adjustment was used in its maximum ASP-on mode. (5) ZETA: A Maico SP345 BTE hearing aid with the ZETA II noise reduction circuitry was used in its ZETA-on mode.

Figure 2 provides the frequency response of the Phonic Ear 805CD2 in the broadband frequency-response setting, the Bosch Star 33PP-ANR in the ASP-off setting, and the Maico SP345 in the ZETA-off setting. These three hearing aids were chosen since they provide similar linear mode frequency responses.

Procedure

A simple up-down adaptive procedure was used to estimate the 50 percent point on the performance-intensity function. The intensity

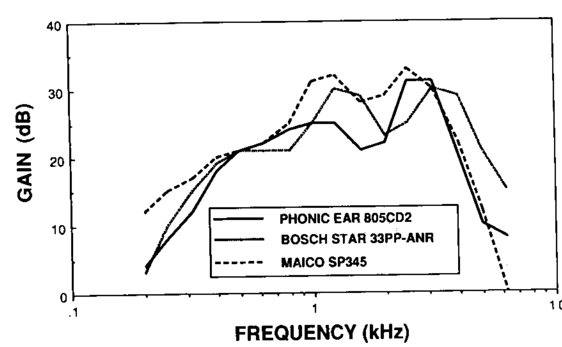

Figure 2 Frequency response measured with 60 dB SPL input and recorded in the 2cc coupler of the three hearing aids in their respective linear modes.

level of the speech was fixed at 67 dB SPL, with the level of the cafeteria noise varied in 2 dB steps. A test run commenced with the signal-to-noise ratio (S/N) set at +12 dB. Testing continued until 10 reversals occurred. The mean of the final six reversals was taken as the estimate of the 50 percent point on the performance-intensity function. For each subject, a practice run was completed for each ear using the linear aid. The ear demonstrating the better performance (lower S/N for 50 percent-correct-performance) was determined to be the test ear. A test run was then completed using each of the five aided arrangements. The order of testing for the five aided conditions was varied across subjects. The subject was encouraged to adjust the volume control wheel of the aid at any time during a test run in order to maintain a "clear and comfortable" signal. All of the subjects chose to adjust the level during the first few reversals, not making any changes in volume control wheel position after that time.

Results

Figure 3 provides the mean S/N (and the standard error of the mean) required for 50 percent-correct recognition of the monosyllabic words for each of the five test conditions. The high-pass condition yielded the lowest S/N (best performance) and the Linear condition yielded the highest S/N. ANOVA (one-factor repeated measures) results yielded a significant (p^{7} 0.05) treatment effect. Follow-up mean comparison results (Tukey procedure at p^{7} 0.1) generally supported the grouping of the four noise reduction techniques as being statistically equivalent to one another and significantly different from the Linear condition. The only exception to this structure was that the ASP mean was not significantly different from the linear mean.

Figure 4 provides the S/N results for each of the 16 subjects. In this Figure, each horizontal line represents the results from one subject. The position on the line reflects the obtained S/N for each indicated hearing aid condition (L-linear, H-high-pass, D-directional, A-ASP, and Z-ZETA). As can be seen, for some subjects performance varied greatly from device to device. For other subjects, several of the devices provided very similar obtained S/Ns. For subjects 1, 7, 8, 9, 10, 12, 14, and 16 one superior noise reduction technique is easily identified. However, for subjects 2, 3, 4, 5, 6, 11, 13, and 15 it is more difficult to demonstrate one particular scheme as being clearly superior. It is also important to note that each of the four noise reduction techniques was ranked first at least twice. Further, each of the four techniques was ranked below linear amplification at least twice.

It should be noted that two of the evaluated noise control hearing aids (ASP & ZETA) adaptively varied their frequency response based on the level and spectral characteristics of the background noise. As the level of the low-frequency dominated cafeteria noise increased,

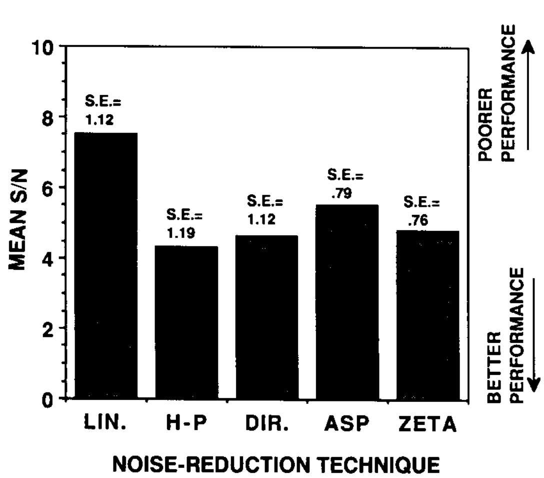

Figure 3 The mean (n=16) S/N required for 50 percent-correct monosyllabic word recognition obtained in each of the aided conditions.

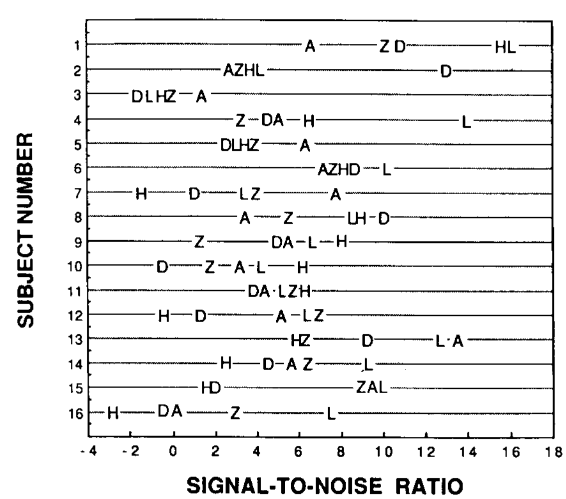

Figure 4 The S/N obtained in each of the aided conditions by each of the 16 subjects (L=linear, H=high-pass, D=directional, A=ASP, Z=ZETA).

the amount of low-frequency cut in the frequency response was increased. Since the testing paradigm used in Experiment I required trial-to-trial changes in the level of the cafeteria noise, it is likely that the amount of noise suppression provided by these two test aids also varied from trial to trial. There is evidence to suggest that this trial-to-trial difference in the frequency response of the ASP and ZETA aids did not appreciably affect the results. If there were a bias, it would be expected that the adaptively controlled aids would be relatively more effective at higher noise levels. Thus, a subject requiring an overall higher S/N (lower noise level) would be expected to rank the nonadaptive aids (high-pass and directional) relatively higher than the adaptive aids. Conversely, at higher noise levels, the adaptive aids would be expected to be relatively more effective. This hypothesis was evaluated by correlating hearing aid rank with S/N across the 16 subjects for each of the four noise reduction aids. (The S/N used was the average S/N obtained across the four noise reduction aids. This measure is essentially an estimate of the general noise sensitivity of each particular subject.) The results revealed correlations that were opposite in sign than were expected. In other words, higher rankings in the nonadaptive aids were associated with lower overall S/Ns and higher rankings with the adaptive aids were associated with higher overall S/Ns. This negative result can be confirmed by viewing individual test cases. Note the performance of Subject 1 in Figure 4. This subject required, overall, much lower noise levels than the other subjects. However, this subject ranked the two adaptive aids higher than the two nonadaptive aids. In contrast, Subjects 3 and 16, who required the lowest S/Ns (tolerated higher noise levels) ranked the nonadaptive aids higher than the adaptive aids.

EXPERIMENT II

Rationale

The results from Experiment I confirmed that noise reduction technology can improve performance in noise for elderly listeners. However, the materials used in Experiment I and in previous investigations consisted of single, isolated words presented auditorily only. Since other cue information is available in most normal communication situations (such as visual information, linguistic and contextual cues, etc.), it was considered possible that the benefit provided by noise reduction technology may be redundant to the benefit available via other, extra-auditory cue sources. Therefore, nose reduction technology was evaluated in a situation more representative of normal communicative environments.

Method

Hearing Aids

Given that the ZETA aid provided mean performance statistically indistinguishable from the best aided condition from Experiment I and given that the ZETA aid provided the least variability from subject to subject, this hearing aid was chosen to be further compared to linear amplification in a follow-up investigation.

Subjects

Five of the original 16 subjects were recalled for the follow-up study. Each of the five obtained either a first or second ranking with the ZETA aid in Experiment I.

Materials

The subjects provided responses to meaningful sentences from the Johns Hopkins Lipreading Corpus (Bernstein and Eberhardt, 1986). These materials were presented via a laser videodisc player with a 26 inch color monitor positioned 1.5 meters in front of the subject. The sentences were presented in a background of cafeteria noise with both the speech and noise presented in the soundfield at 0 degrees azimuth (speaker immediately above the video monitor).

Procedure

The subjects listened while wearing the linear aid and while wearing the ZETA aid. The subject attempted to repeat the complete sentences with and without the benefit of visual and contextual cues. In the noncued situation, the screen of the video monitor was covered. In the cued situation, the screen of the video monitor was uncovered. In addition, in the cued situation, the subject was provided with a written version of a lead-in sentence prior to each test sentence. The subject was required to read the lead-in sentence aloud before the test sentence was presented. These lead-in sentences were constructed in order to provide logical topical cues for the following test sentence. For example:

Lead-in sentence: "Please contact me as soon as possible."

Test sentence: "I'll wait here for your call."

The speech material was presented at 67 dB SPL, with the cafeteria noise presented at two levels: 67 dB SPL (0 dB S/N) and at 59 dB SPL (+ 8 dB S/N). Two hearing aids (linear/ZETA), two cue situations (noncued/cued), and two S/Ns (0 dB/ +8 dB) yielded eight total listening conditions. In each listening condition, the subject was presented with 50 key words distributed across a list of 11 to 14 sentences. The order of testing for the eight listening conditions and the match of sentence list to listening condition were varied from subject to subject. Performance was measured as percent-correct for the key words.

Results

Figure 5 provides the results from Experiment II. As can be seen, at both S/Ns and whether cues were present or not, the ZETA hearing aid allowed for improved mean performance when compared to the Linear hearing aid. A three-factor repeated measures ANOVA revealed significant (p^7 0.1) S/N, cue situation, and hearing aid type main effects.

GENERAL DISCUSSION

In general, it appears that noise reduction technology can improve performance for elderly hearing aid candidates when compared to simple, broadband, linear amplification. The more traditional noise reduction techniques (high-pass amplification and directional microphones) provide the same magnitude of benefit as compared to the newer techniques (ZETA and ASP). The difference may be that the newer techniques provide more flexibility than the more traditional techniques. For example, ZETA circuitry, theoretically, will have an effect for noises other than just those with primary energy in the low frequencies (Graupe et al, 1986). ASP and ZETA circuitry will allow for broadband amplification when minimal low-frequency noise is present, which may provide a more acceptable amplified signal. High-Pass amplification will always filter out low-frequency information, even in quiet listening situations. Neither of the newer techniques are limited by the directional relation of the speech and noise. In contrast, directional microphones lose their effectiveness once the source of the noise moves from 180 degrees azimuth or when the speech moves from 0 degrees azimuth.

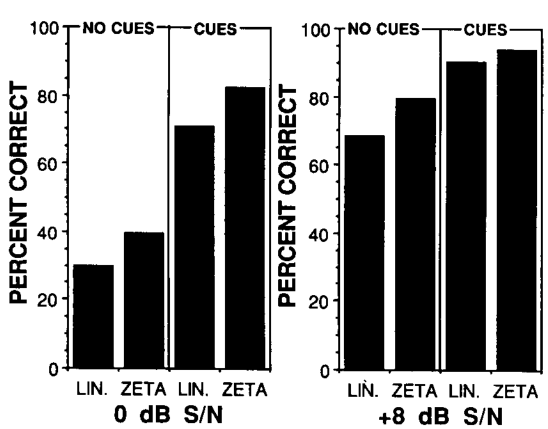

Figure 5 Mean (n=5) percent-correct for key words in sentences for each of the eight listening conditions in Experiment II.

If one were to make a general recommendation for the noise reduction technique of choice based upon mean data, the recommended technique would have to be ZETA circuitry, given its good average performance, low subject-to-subject variability, and its situational flexibility. However, given the similar mean performance of the four different noise reduction techniques and, more importantly, given the individual ranking data presented in Figure 4, it is clear that, if at all possible, a variety of noise reduction techniques should be evaluated for each patient. The results in Figure 4 demonstrate that, for many subjects, one specific type of noise reduction technology can be identified as providing superior benefit.

It should be noted that no combination conditions were used in this investigation. In other words, it is quite possible that the use of more than one noise reduction technique may lead to further improvement in performance (see, for example, the work of Hawkins and Yacullo [1984] for the combined effects of directional microphones and binaural amplification). Other than the combination of ASP and ZETA circuitry, most other combinations are technically and practically possible.

The results in Figure 5 reveal that whether listening is performed in a difficult (0 dB S/N) or moderate (+8 dB S/N) noise environment, the benefit provided by ZETA circuitry is still present even if the listener can have access to visual and contextual cues. In other words, the benefit provided by hardware techniques is additive to the benefit provided by "non-hardware-based" techniques. The clinician needs to alert the new hearing aid user to continue to seek out and use this supplementary cue information even when fit with state of the art noise reduction circuitry.

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