Performance With an Adaptive Frequency Response Hearing Aid in a Sample of Elderly Hearing-Impaired Listeners

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ABSTRACT

This study assessed the efficacy of an adaptive frequency response hearing aid (AFR) for improving speech perception ability in noise among a group of elderly hearing-impaired listeners. A speech recognition task, self-assessed speech intelligibility task, and qualitative judgment task were administered to examine subtle differences in the effects of the AFR "signal processing" versus linear amplification. Group scores showed statistically significant improvement with AFR processing on the speech recognition task involving high-predictability sentences, but not on any other measures. However, there was a trend toward improved scores with AFR processing for low-predictability sentences as well. These results suggest that AFR circuitry may be most useful for enhancing recognition of speech in high-cue contexts. Wide individual subject variability was observed on all measures. This demonstrates the importance of evaluating the effectiveness of noise reduction hearing aids on an individual basis and with more than one task. (Ear Hear 13 4:255–262)

ELDERLY PEOPLE COMPRISE the largest population with sensorineural hearing loss in the U.S. (Schoenborn & Marano, 1988), yet their acceptance rate of hearing aids is relatively low (Ries, 1982; Salomon, Vesterager, & Jagd, 1988; Upfold & Wilson, 1983). One reason for the low acceptance rate is that many hearing aids do not alleviate the older person's greatest communication difficulty: understanding speech in noise. Dubno, Dirks, and Morgan (1984) found that elderly people with only mild hearing losses demonstrate serious speech recognition deficits in the presence of noise. Moreover, these deficits exceeded the speech recognition scores that were predicted by Articulation Index calculations (ANSI, 1969).

The environmental signal to noise (S/N) ratio is a critical factor that affects speech recognition ability. Numerous studies have shown that hearing-impaired listeners' speech recognition scores decrease considerably with S/N ratios less than approximately +12 dB (Finitzo-Hieber & Tillman, 1978; Jokinen, 1973; Nabelek & Mason, 1981). However, everyday listening situations are characterized by S/N ratios of +5 to +8 dB (Pearsons, Bennett, & Fidell, 1977) and, therefore, represent very difficult listening conditions for hearing-impaired listeners. An improvement in S/N ratio is, therefore, a primary goal for amplification devices in order to minimize the handicapping effects of hearing loss in typical listening environments (Plomp, 1978).

Traditional linear amplification often provides limited benefit to elderly hearing-impaired people because it preserves the environmental S/N ratio in the amplified signal. Self-reports of perceived hearing aid benefit by elderly people reflect this difficulty in listening in noise. In a survey conducted by Franks and Beckmann (1985), one of the highest ranked reasons for hearing aid rejection by elderly people was that the hearing aid amplifies noise.

Hearing aid manufacturers have developed a variety of noise reduction hearing aids that attempt to address the problems encountered by hearing-impaired listeners in background noise and low S/N ratios. The latest technology includes instruments that incorporate adaptive frequency response (AFR) signal processing technology (also called adaptive response technology or automatic signal processing; Fabry & Walden, 1990). This technique changes the frequency response of the hearing aid in response to changes in the listening environment. The basic premise is that the ideal frequency response for a particular hearing-impaired listener varies with the characteristics of the acoustic environment. In many of these devices, a high-pass filter is activated when continuous, low-frequency energy is detected. Because the filtering attenuates the continuous low-frequency energy (which presumably is noise), the output of the hearing aid may increase the effective S/N ratio. These types of systems have potential merit because an increase in the environmental S/N ratio should improve a hearing aid user's speech recognition ability.

Most recent evaluations of adaptive signal processing devices have assessed their efficacy with young adult

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hearing-impaired listeners. The consistent findings with one AFR circuit are that the device usually did not improve speech recognition when there was spectral overlap between the speech signal and the background noise (Klein, 1989; Van Tasell, Larsen, & Fabry, 1988). This circuit, the Zeta Noise Blocker (ZNB), analyzes the time and frequency characteristics of the incoming signal and reduces the gain of the low-frequency region if it determines that noise is present (i.e., low-frequency energy is constant over time) (Grosspietsch, 1987). Van Tasell et al (1988) found that a prototype of the ZNB did not improve young hearing-impaired listeners' speech recognition thresholds in speech noise. However, in the presence of low-pass noise, performance improved for two of the five subjects. Klein (1989) evaluated the effects of a ZNB circuit incorporated in a commercial hearing aid and found that performance with the ZNB circuit activated was comparable to performance with a linear hearing aid. This finding suggests that the ZNB circuit did not improve the S/N ratio for the young hearing-impaired listeners.

The effectiveness of noise reduction hearing aids has also been evaluated for elderly hearing-impaired listeners. Schum (1990) compared elderly listeners' word recognition scores in cafeteria noise using five aided conditions: linear amplification, high-pass amplification, directional microphone circuitry, automatic signal processing circuitry, and ZNB-II noise reduction circuitry. Performance improved with all four noise reduction hearing aids compared to the linear hearing aid, although there were no differences in average subject performance between the four experimental hearing aids. Schum noted that individual subject performance varied considerably with each hearing aid, suggesting that one hearing aid among the four evaluated was not superior for all elderly hearing-impaired subjects.

A somewhat different type of AFR hearing aid circuit will be evaluated in the present study. This circuit splits the incoming signal into low- and high-frequency bands and automatically reduces low-frequency amplification while increasing high-frequency amplification when the intensity of the low-frequency input to the hearing aid exceeds the filter limit. (Note that all AFR circuits do not function in this manner.) An amplification device of this type is expected to improve speech recognition in noise for several reasons: the reduction of low-frequency amplification should decrease the masking effects of low-frequency noise, the increase of high-frequency amplification should improve reception of weak, high-frequency consonants, and both frequency response manipulations should improve the effective S/N ratio at the user's ear. Increments in consonant energy have been shown previously to improve elderly hearing-impaired listeners' nonsense syllable recognition performance in noise (Gordon-Salant, 1987b). To date, the effectiveness of this type of AFR hearing aid circuitry for improving hearing-impaired listener's speech recognition performance has not been reported.

Although young and elderly hearing-impaired individuals may benefit from the acoustic enhancement of the AFR circuitry described above, the present study assessed the performance of elderly hearing-impaired listeners exclusively. Elderly subjects were selected for evaluation because of the high prevalence rate of hearing impairment in this population (Hotchkiss, 1989), the high rate of hearing aid rejection among elderly people, and the unique speech recognition deficits that elderly people may experience in poor acoustic environments (Dubno et al, 1984; Gordon-Salant, 1987a; Helfer & Wilber, 1990). Thus, the benefits of AFR hearing aid circuitry may be particularly useful for elderly hearing-impaired people.

The present series of experiments assessed the benefit that elderly listeners receive from an AFR hearing aid in its "signal processing" (SP) mode compared to linear amplification. Performance benefit was evaluated in noise using three measures: speech recognition judgments, subjective ratings of speech intelligibility, and qualitative judgments of speech signals. Three different measures of hearing aid benefit were used in order to identify subtle differences in hearing aid performance that might not be revealed with only one method.

METHOD

Subjects

Ten subjects, between the ages of 65 and 80 yr (mean = 76 years), participated in the experiment. Each subject had a mild to moderate, sloping sensorineural hearing loss from 250 through 4000 Hz. Figure 1 shows the mean pure-tone audiogram of the subjects. All subjects were experienced users of linear amplification. Hearing aid experience ranged from 2 mo to 10 yr among these subjects. Examination of subject history and tympanograms revealed no evidence of hearing loss due to noise exposure, middle ear pathology, or known otological disease, so that the presumed cause of hearing loss was presbycusis. Prior hearing aid experience was necessary for purposes of subjective evaluation.

Hearing Aid

The hearing aid used in this study was the Audiotone MSP hearing aid. This hearing aid can be switched from linear amplification (L) to SP via a toggle switch located under the volume control wheel. When the hearing aid is in the linear mode, the specifications are as follows: HFA SSPL 90 = 123 dB SPL; full-on gain = 48 dB; frequency response = 336 to 5100 Hz. Internal controls for frequency response adjustment

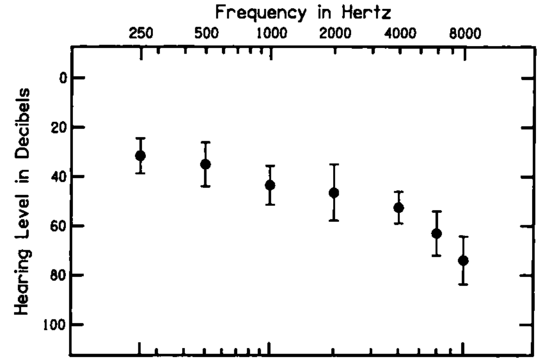

Figure 1. Pure-tone threshold means and SDs for the 10 subjects.

are not available with the Audiotone MSP hearing aid in either the L or SP modes.

According to Staab and Nunley (1987), the Audiotone MSP hearing aid in its SP mode continuously samples the incoming signal and adjusts the frequency response of the output accordingly. In quiet, the full spectrum of the input is amplified linearly. When the input to the hearing aid contains low-frequency energy that exceeds an activation level, the gain of the low frequencies is reduced by as much as 30 dB. In addition, the gain of the high frequencies may be increased by as much as 20 dB at 2000 Hz (Staab & Nunley, 1987). The manufacturer's specifications indicate that other factors affecting the magnitude of low-frequency reduction and high-frequency amplification in the SP mode include the input signal level, volume control setting, and internal threshold control setting.

Test Materials

The speech stimuli used were the sentence lists from the Revised Speech Perception in Noise (R-SPIN) test, the Speech Intelligibility Rating (SIR) test, and a connected discourse passage (the Davy Crockett story, usually used as a competing signal in the Synthetic Sentence Identification test).

The R-SPIN test was designed to assess word recognition in low- and high-cue sentence contexts (Bilger, Neutzel, Rabinowitz, & Rzeczkowski, 1984; Kalikow, Stevens, & Elliott, 1977). There are 8 lists of 50 sentences each. Half of the sentences on each list have high predictability key words, in which semantic, prosodic, and syntactic cues in the sentence aid the listener's identification of the key word. The remaining sentences have low-predictability key words, which require reception of the acoustic cues for accurate word recognition. In the present experiment, the R-SPIN sentence lists were presented in a 12-talker babble background at +8 and 0 dB S/N ratios to assess each subject's ability to understand running speech and individual words while using the Audiotone MSP hearing aid.

The second test was the SIR test, developed by Cox and McDaniel (1989). This test was designed for use in clinical comparisons of hearing aid conditions. The test consists of 20 passages of connected speech presented in a background of multitalker babble. After listening to each passage, the subject rates the estimated level of words understood on a scale of 0 to 10, where 0 = no words were understood, 5 = half of the words were understood, and 10 = all words were understood. The resulting scores indicate the intelligibility of speech under various hearing aid conditions, as expressed by each subject. Before rating the intelligibility of each passage, a test S/N ratio was determined by playing a 20 sec portion of speech and adjusting the S/N ratio until one is identified at which two to three ratings of 7 or 8 are obtained. Once the test S/N ratio has been determined, three 48 sec passages are played for each hearing aid condition and the speech intelligibility rating is obtained after each passage. The test was included to enable subjective evaluation of speech intelligibility with the AFR hearing aid.

The third test, qualitative judgment, was conducted following procedures described by Gabrielsson, Schenkman, and Hagerman (1988). Listeners' judgments on five perceptual scales and an overall impression scale were evaluated while listening to connected discourse in quiet and in the presence of multitalker babble noise. The five perceptual scales were selected on the basis of high interindividual reliability and high correlations with the overall impression scale (Gabrielsson et al, 1988). These scales included fullness, brightness, nearness, spaciousness, and clarity. Subjects were given written instructions that included definitions of the five perceptual dimensions and examples of rating scale assignments. Additional clarification was provided at the subject's request. The five perceptual scales were used to aid each subject in formulating a total impression about the hearing aid in each mode. Specifically, the subjects were instructed to provide a score on the total impression scale that was representative of an average of the ratings on the five perceptual scales. In the overall impression scale, a rating of 0 indicated very poor quality and a rating of 10 indicated very high quality. Subjects listened to the discourse (Davy Crockett story) with the hearing aid in the L and SP modes and made judgments regarding the sound quality of the connected discourse as processed by the hearing aid in each mode.

Procedure

Preliminary tests included air conduction audiometry and tympanometry. After these tests, the Audiotone MSP hearing aid was placed on each subject and coupled to the subject's own earmold or a Comply earmold. The internal threshold control was set at 65 dB. A prescriptive fitting procedure was not used because the Audiotone MSP hearing aid does not have an adjustment for frequency response. The volume control wheel of the hearing aid was set to a comfortable level while the subject listened to a tape recording of connected discourse presented at 75 dB SPL. This input level was equivalent to the level of the speech stimuli used in the experiment. Subjects were not permitted to change the volume control setting during the experimental procedures.

Real ear analysis was conducted with a Fonix 6400 Real Ear Analyzer following the manufacturer's recommended procedures. A 75 dB SPL speech-weighted composite signal was presented through the loudspeaker at 12 in distance and 45° azimuth from the subject's test ear. The 75 dB SPL signal was chosen for this analysis to represent the overall level of the speech stimuli used in the experiment. The probe and reference microphones were located at 4 mm insertion depth into the ear canal and just above the pinna, respectively.

The aided real ear responses were compared in the L and SP modes to confirm that the AFR circuit was activated with a 75 dB SPL signal. Table 1 presents the aided responses in the two hearing aid modes for the 10 subjects. This table shows that for this input signal, low-frequency amplification was reduced for all subjects and high-frequency amplification was increased for several subjects in the SP mode relative to the L mode. The magnitude of these changes also varied among the subjects. It should be noted that according to the manufacturer, it is difficult to test the performance of the Audiotone MSP aid in the SP mode on traditional hearing aid analyzers because of the dynamic nature of the aid in different noise environments (Staab & Nunley, 1987). The real ear gain values in the L mode agree with those predicted by the R-National Acoustic Laboratories' prescriptive fitting formula (Byrne & Dillon, 1986) within 5 dB (250–4000 Hz) for five subjects and within 10 dB (250–4000 Hz) for another two subjects.

In all of the experimental conditions, the signals were prerecorded on one channel of reel to reel tape and the babble was prerecorded on the second channel of the tape. The signals and noise were played back on an Otari 5050B tape deck, separately amplified (Crown D-75), attenuated (Hewlett-Packard 350D), and presented via JBL (Model 4311) loudspeakers. The loudspeakers were each positioned 1 m from the subject at 0° azimuth and 180° azimuth. The speech signals were always presented to the subject at 0° azimuth, and the noise at 180° azimuth.

Table 1. Insertion gain of the Audiotone MSP hearing aid for L and SP modes.

Subject	Frequency (in Hz) 250	500	1000	2000	4000	6000	8000
1							
L	3	11	25	29	23	10	10
SP	4	5	20	29	23	11	12
2							
L	5	12	20	21	23	0	0
SP	4	5	10	20	23	0	5
3							
L	3	11	23	32	30	0	4
SP	4	5	18	30	30	0	4
4							
L	2	11	23	22	22	0	5
SP	2	4	18	22	21	0	7
5							
L	3	10	20	25	20	0	0
SP	3	5	21	30	25	0	0
6							
L	3	10	21	29	20	0	0
SP	3	7	18	28	20	0	0
7							
L	2	10	21	25	10	0	0
SP	2	5	13	25	10	0	0
8							
L	4	12	25	21	13	0	0
SP	4	7	21	23	20	0	0
9							
L	5	10	25	32	30	10	0
SP	5	5	18	30	27	10	0
10							
L	5	11	22	26	20	0	0
SP	3	5	18	26	20	0	0

The R-SPIN sentence lists were presented to each subject at 75 dB SPL in the multitalker babble background at a 0 dB S/N ratio and at a +8 dB S/N ratio. Subjects listened in each of these two S/N ratio conditions in each of the two hearing aid modes (L and SP). Different lists were assigned to the different conditions and randomly assigned across subjects. In addition, the listening conditions and hearing aid conditions were randomized. The signal presentation level was fixed at 75 dB SPL to represent normal to loud conversational speech and to ensure that the SP circuit would be activated during testing.

Before beginning the SIR test with the experimental hearing aid, the test S/N ratio was determined with the subject's own hearing aid adjusted to its use settings until the subject arrived at the criterion rating, between 7 and 8 (Cox & McDaniel, 1989). Once the test S/N ratio was established, the Audiotone MSP hearing aid was replaced on the subject. The setting of the test S/N ratio with the subject's own hearing aid was used in order to have a fixed S/N ratio setting for both conditions involving the Audiotone MSP hearing aid. During the SIR test, the passages were presented at 75 dB SPL. Subjects rated the intelligibility of the passages with the experimental hearing aid in both the L and SP modes.

The stimulus for the qualitative judgment task was presented at 75 dB SPL in quiet and in the presence of multitalker babble (0 dB S/N ratio). Subjects listened to the discourse with the hearing aid in the L and SP modes, and using the six scales, rated the sound quality of the discourse as processed by the hearing aid in each mode. One judgment per perceptual dimension was obtained for each hearing aid mode × listening condition from each subject. The experimental measures, R-SPIN sentence recognition, SIR, and qualitative judgments, were presented to each subject in randomized order. All testing was completed in one 3-hr session. Subjects were given breaks at intervals during the test session to prevent the effects of fatigue on data collection.

RESULTS

Comparison of Group Mean Scores

Group mean R-SPIN recognition scores are shown in Tables 2 and 3. Multivariate analysis of variance (MANOVA) procedures were completed separately on the arc-sine transformed R-SPIN high- and low-predictability sentence scores. A randomized block design was used with two between-subject variables (noise and hearing aid condition) (Kirk, 1968). The results for the high-predictability scores revealed significant main effects of noise ($F = 37.55$, $p < 0.001$), hearing aid mode ($F = 9.14$, $p < 0.014$), and subject ($F = 6.91$, $p < 0.004$). There were no significant interactions. Results for the low-predictability sentence scores revealed significant interactions between noise and subject and between hearing aid mode and subject. The main effects of noise and hearing aid mode were reanalyzed with revised error terms: the noise effect was analyzed by a noise by subject error term and the hearing aid effect was analyzed by a hearing aid mode by subject error term. The results revealed a significant main effect of noise ($F = 18.65$, $p < 0.002$). A significant effect of hearing aid mode was not observed.

Analyses of both high- and low-predictability sentence scores revealed a significant main effect for noise. As expected, all subjects demonstrated higher word recognition scores in the +8 dB S/N ratio listening condition compared to the 0 dB S/N ratio condition in both hearing aid modes.

Table 2. Mean R-SPIN scores on high-predictability sentences.

Condition	Hearing Aid Mode L	SP
+8 dB S/N Ratio		
Mean	90.8%	93.6%
SD	7.6	4.8
0 dB S/N Ratio		
Mean	64.4%	81.2%
SD	27.4	15.3

Table 3. Mean R-SPIN scores on low-predictability sentences.

Condition	Hearing Aid Mode L	SP
+8 dB S/N Ratio		
Mean	48.8%	56.4%
SD	13.6	14.4
0 dB S/N Ratio		
Mean	28.4%	37.2%
SD	17.5	19.8

The significant main effect for hearing aid with the high-predictability sentences was associated with higher scores in the SP mode than in the L mode.

The mean intelligibility ratings from the SIR test, obtained with the hearing aid in the L and SP modes, are shown in Table 4. These scores were also arc-sine transformed before *t*-test analysis (Cox, Alexander, & Rivera, 1991). The *t*-test revealed that the difference between the means was not significant.

Table 5 displays the group mean qualitative judgment ratings from the total impression scale. MANOVA procedures were completed on these total impression judgment scores only. The results revealed a significant main effect of noise ($F = 9.26, p < 0.014$), but not of hearing aid mode.

Correlations Between Types of Measures

Correlations between the arc-sine transformed R-SPIN scores and intelligibility ratings were calculated and are shown in Table 6. The correlations between the scores were generally low and ranged from −0.43 to 0.40.

DISCUSSION

Speech Recognition

The first issue examined was whether or not speech recognition ability in noise improves when hearing-impaired listeners use the AFR hearing aid in the SP mode compared to the L mode. Based on the analysis of group data, speech recognition ability does not improve significantly with the AFR circuit when recognition of the stimuli requires accurate reception of high-frequency acoustic cues, as is the case with the low-predictability R-SPIN sentences. However, improvement with the AFR circuitry does occur when contextual cues are provided to aid in recognition of the stimulus word, as shown with the high-predictability R-SPIN scores.

The results of this study are in general agreement with the results of earlier studies examining the efficacy of other AFR circuits. Van Tasell et al (1988), Klein (1989), and Tyler and Kuk (1989) all concluded that the signal processor in the ZNB does not consistently improve speech recognition ability in noise, as measured with monosyllabic words and nonsense syllables in various types of background noise. The stimuli used in these previous studies are similar in nature to the R-SPIN low-predictability sentences because recognition of such stimuli requires reception of high-frequency acoustic cues. In addition, multitalker babble was used as one type of noise. Therefore, the Audiotone MSP, like the ZNB, does not consistently improve speech recognition ability in the presence of background noise composed of frequencies in the speech range when contextual cues are not available. This is problematic, because speech babble is a common and very interfering type of noise.

Nevertheless, other researchers (Schum, 1990; Stein & Dempesy-Hart, 1984) have demonstrated improvement in word recognition ability in noise with the ZNB. Numerous methodological differences between studies could account for these different findings. For example, in the Stein and Dempesy-Hart study, four of the five subjects were much younger than the subjects of the present investigation and the oldest subject did not demonstrate any improvement. Subjects were also permitted to change the volume control adjustment between hearing aid conditions in this previous study, but not in the present investigation. Although the subjects in Schum's study were in the same age range as the subjects in the present study, most of them were inexperienced hearing aid users. As suggested by Halligan and Mercer (1987), the experienced hearing aid users in the present investigation may not have derived consistent benefit from the signal processing circuit because the overall power may have seemed lower. Different types of competition also were used in these studies (multitalker babble versus cafeteria noise), which may have produced variable masking effects.

Another source of different results between the present experiment and these two previous studies is the use of different SP hearing aids: ZNB versus Audiotone MSP. As discussed earlier, the ZNB functions in a different manner than the Audiotone MSP hearing aid. However, it is difficult to determine whether the improvements demonstrated by the subjects of these two studies are due to the manner in which the SP hearing

Table 4. Mean ratings on the SIR test.

	Hearing Aid Mode	
	L	SP
Mean	6.34	7.04
SD	3.6	3.2

Table 5. Mean ratings on the qualitative judgment task.

	Hearing Aid Mode	
Condition	L	SP
Quiet		
Mean	8.6	8.6
SD	1.6	1.6
0 dB S/N Ratio		
Mean	6.6	7.2
SD	2.6	1.9

Table 6. Correlations between the SIR ratings and the R-SPIN word recognition scores.

Score 1	Score 2	Correlation (*r*)
SIR (L)	R-SPIN +8 − HP (L)	−0.43
SIR (L)	R-SPIN +8 − LP (L)	0.40
SIR (L)	R-SPIN 0 − HP (L)	0.14
SIR (L)	R-SPIN 0 − LP (L)	0.18
SIR (SP)	R-SPIN +8 − HP (SP)	0.08
SIR (SP)	R-SPIN +8 − LP (SP)	0.11
SIR (SP)	R-SPIN 0 − HP (SP)	0.16
SIR (SP)	R-SPIN 0 − LP (SP)	−0.13

aids function or to the methodological differences between the different experiments.

SIR

The second issue examined was whether or not listener-assessed speech intelligibility would be higher with AFR enhancement than with linear amplification. The results indicate that listeners did not assess speech intelligibility to be different with the SP mode compared to the L mode. This finding could be partially accounted for by a ceiling effect observed for two subjects. The procedure of establishing the test S/N ratio while using the subject's own hearing aid inadvertently enabled two subjects to obtain scores of 10 in the L mode, which obscured any observation of improvement in the SP mode. An analysis of the individual scores of the remaining eight subjects revealed that only two subjects demonstrated a higher score in the SP mode than the L mode that exceeded the critical difference of 2.1 interval scales (D. M. McDaniel, personal communication).

One explanation for these results is that the two aided conditions did not produce noticeable perceptual differences in the amplified signal. Alternatively, the SIR test may not be sufficiently sensitive to reveal differences in aided speech intellibility by elderly listeners. Cox, Alexander, and Rivera (1991) also examined elderly hearing-impaired subjects and found no differences in SIR scores across three aided listening conditions.

Qualitative Judgment

The final issue examined was whether or not listeners would prefer the sound quality of speech processed by AFR circuitry compared to linear amplification. This issue was particularly important because elderly people frequently reject hearing aid use on the basis of perceived amplified sound quality. The present results reveal that subjects made similar judgments of quality with the hearing aid in both the L and SP modes. The judgment of overall quality of the hearing aid in either mode was "good" in the quiet condition and "fair" in the noise condition.

Previous studies have indicated that quality judgment tasks are useful in determining hearing aid users' preferences among several amplification devices (Gabrielsson et al, 1988; Jeffers, 1960; Punch & Parker, 1981; Tecca & Goldstein, 1984). The task selected for this study was derived from a task designed and tested by Gabrielsson et al (1988). In that investigation, the authors concluded that sound quality ratings provided better distinctions between different hearing aids than speech recognition performance. In the present study, the subjects generally did not perceive differences in the quality of the signal as processed in the SP and L modes.

One possible explanation for these results is that the qualitative judgment task was difficult for the subjects. The concepts of spaciousness and brightness were too abstract, and the judgments on these scales may have influenced the final rating of overall impression. It is also possible that each elderly subject produced variable results on the perceptual judgments, which could have contributed to nonsignificant findings. Gabrielsson et al (1988) reported that their normal-hearing and young hearing-impaired subjects showed highly reliable responses on the six scales used in the present study. However, the reliability of performance on these measures by elderly hearing-impaired subjects has not yet been investigated.

Comparison Among Measures

Although some studies have demonstrated high correlations between speech recognition performance and listener-assessed judgments of intelligibility (Cox et al, 1991; Punch & Parker, 1981; Speaks, Parker, Harris, & Kuhl, 1972), others have not (Tecca & Goldstein, 1984). The present investigation also found low correlations between the different measures. The stimuli of the SIR test are similar to the R-SPIN high-predictability sentences in that contextual cues are available. However, the specific stimuli and tasks are different, which could result in differences in performance. A similar observation was made regarding the use of different stimuli for the two tasks in the study conducted by Tecca and Goldstein. Indeed, Cox et al (1991) used identical speech stimuli for the objective speech recognition and subjective speech intelligibility tasks and found high correlations between the two measures. The present results indicate that different aspects of aided speech perception are evaluated on the R-SPIN speech recognition task and the SIR test of self-assessed speech intelligibility.

Comparison of MANOVA results across tasks indicates that "objective" word recognition testing (i.e., the R-SPIN sentence lists) is most sensitive for revealing improvement in speech recognition ability with AFR circuitry, but primarily for high-predictability sentences. Listener-assessed judgments of intelligibility are less likely to reveal improvement. A similar observation was made in the study by Cox et al (1991). The qualitative judgment task also was not sensitive for revealing differences in performance in the different hearing aid modes.

Individual Performance

Individual variability characterized the performance of the subjects on the different measures, as shown by the significant subjects effect in the MANOVA results for the R-SPIN sentences and qualitative judgment task. An informal examination of individual data showed that in comparison to linear amplification, the SP mode produced numerically higher percent correct recognition scores on the low-predictability R-SPIN sentences (both S/N ratios) and the high-predictability sentences (+8 dB S/N ratio) for six subjects, higher scores on the high-predictability sentences (0 dB S/N ratio) for six subjects, higher scores on the high-predictability sentences (0 dB S/N ratio) for seven subjects, differences on the SIR test that exceeded the critical difference for two subjects, and numerically higher quality judgments on the total impression scale in the 0 dB S/N ratio condition for five subjects. Only one subject showed improvement on the quality judgment measure in the quiet condition with the hearing aid in the SP mode. Interestingly, numerically higher scores were obtained by several subjects with the hearing aid in the L mode than the SP mode for the speech recognition tasks (HP-SPIN sentences at +8 dB S/N ratio: $N = 3$ subjects; HP-SPIN sentences at 0 dB S/N ratio: $N = 2$ subjects; LP-SPIN sentences at +8 dB S/N ratio: $N = 4$ subjects; LP-SPIN sentences at 0 dB S/N ratio: $N = 4$ subjects; and the quality judgment task in noise: $N = 3$ subjects).

One possible source of the between-subject variability on each task related to differences in the magnitude of the low-frequency cut and corresponding high-frequency boost received by the different subjects in the SP mode. Real ear response measures of the 10 subjects revealed considerable variations in the amount of acoustic enhancement that each subject experienced in the SP mode compared to the L mode with the speech-weighted composite signal. Given that the input spectrum, input signal level, and threshold control setting were constant across subjects in any one condition, the observed variations in acoustic enhancement in the SP mode were most likely associated with the different volume control settings used by the subjects or different ear canal resonances of the subjects. Nevertheless, the subjects who received the most measured high-frequency real ear gain in the SP mode were not necessarily those who showed the most improvement on each measure.

There was also intrasubject variability across the different performance measures. Subjects who demonstrated improved scores on the speech recognition measures with the hearing aid in the SP mode did not always show improvements on the other measures. However, it should be noted that there were few score differences for the SIR test and the qualitative judgment task in quiet. Only two subjects showed consistently higher scores with the hearing aid in the SP mode than in the L mode for the remaining five conditions, and none of the subjects showed consistently lower scores with the hearing aid in the SP mode than in the L mode. One possible explanation for this intrasubject variability is that different amounts of signal processing may have been invoked by the different speech signals and different noise levels used across conditions in this study. A second explanation is that the evaluation procedures may not have been sufficiently sensitive for revealing subject performance differences with the hearing aid in the two modes.

Individual variability in speech recognition performance with noise reduction hearing aids has been noted in other studies (Schum, 1990; Tyler & Kuk, 1989). This underscores the need for evaluating performance with AFR hearing aids with elderly hearing-impaired people on an individual basis.

Summary

The acoustic enhancement created by the AFR hearing aid appears to be most beneficial for improving speech recognition in noise when contextual cues are available. The acoustic enhancement resulting from AFR processing was less sufficient for improving speech recognition performance with low-predictability R-SPIN sentences, although there was a trend toward improved scores. These results suggest that assessment of the benefits of AFR circuitry for clinical and research purposes should incorporate the use of speech materials that include both high- and low-context conditions. The use of either high- or low-context speech materials alone in the present investigation would have produced differing conclusions about the advantages of AFR processing.

The present results, obtained from elderly experienced hearing aid users, do not necessarily generalize to younger hearing-impaired people and/or inexperienced hearing aid users. However, to the extent that the benefits of AFR processing on speech recognition performance can be explained by interactions between the hearing aid's altered frequency response in noise and the listener's pure-tone hearing sensitivity, one could predict that similar benefits of AFR processing would be observed in other individuals with similar audiometric contours. Future research should be conducted to verify this assumption.

The most important finding in the present investigation is that the AFR hearing aid is primarily beneficial in listening conditions that include contextual cues. High-cue context conditions characterize many, but not all, listening situations encountered in everyday life.

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