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Benefit Acclimatization in Elderly Hearing Aid Users

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Abstract

A previous study from this laboratory indicated that the benefit obtained from a hearing aid in a noisy environment might increase over the first few months of hearing aid use. It was hypothesized that this acclimatization of benefit was due to a process in which the individual optimized his/her use of modified or newly available high-frequency acoustic speech cues. This investigation further explored the effect in 22 elderly individuals with mild to moderate sensorineural hearing losses, fitted unilaterally with hearing aids. None of the subjects was a current or recent hearing aid wearer. Speech intelligibility testing over a 12-week post-fitting period indicated that a significant improvement in benefit was seen for the group as a whole, probably beginning after about 6 weeks of regular hearing aid use. However, the magnitude of improvement was very small for most subjects. Only three individuals experienced a dramatic improvement in their benefit for speech in noise over this period. No evidence was found for a specific role of high-frequency cues. Seven subjects participated in a long-term follow-up in which benefit was measured after several months of use of their newly acquired personal hearing aids. Further increase in benefit was noted but was due exclusively to a decline in performance for unaided listening.

Key Words: Benefit, hearing aids, insertion gain, speech intelligibility

Abbreviations: ANOVA = analysis of variance, CST = Connected Speech Test, FCC = final consonant continuance, FCP = final consonant place, FCV = final consonant voicing, ICC = initial consonant continuance, ICP = initial consonant place, ICV = initial consonat voicing, NAL = National Acoustic Laboratories, RAV = rationalized arcsine unit, PLL = preferred listening level, SBR = signal-to-babble ratio, SPAC = Speech Pattern Contrast Test, SPL = sound pressure level, SSPL90 = saturation sound pressure level with a 90-dB input, VHT = vowel height, VPL = vowel place

The overall goal of our research program is to develop a method for predicting hearing aid benefit in advance of the actual hearing aid fitting. In this endeavor, it is important to consider the effects of accommodation to amplified signals during the first few months of hearing aid use. These effects would encompass any improvements in the hearing-impaired individual's ability to discriminate and interpret acoustic cues that have been modified or reintroduced by the new signal processing system. If these effects are large, they could have a substantial impact on the benefit ultimately realized by the individual. We were aware of anecdotal evidence suggesting that a period of adjustment was necessary to obtain maximum benefit from a hearing aid but it was not clear whether this adjustment was mainly physical or whether it included a psychoacoustic component in which understanding of amplified speech was somehow optimized. The results of our first study of this matter were reported in 1992 (Cox and Alexander, 1992). The present article reports the results of a follow-up investigation.

Cox and Alexander (1992) studied a group comprising eight novice hearing aid users and four experienced hearing aid users. All were fitted with new hearing aids and followed for the

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first 10 weeks of hearing aid use. Speech intelligibility was tested at the time of fitting and after 10 weeks of hearing aid use in each of four types of simulated listening environments. The four environments included a simulated living room, a simulated classroom, and two versions of a simulated cocktail party or social event. Because the main complaint of potential hearing aid wearers is usually related to understanding speech in noisy environments, we were especially interested in the results obtained in the simulated cocktail party. The results observed in the two party environments provided much of the impetus for this follow-up study.

In the simulated party environments, speech level was fairly high (67 dB SPL) but the signal-to-babble ratio (SBR) was relatively poor (2.0 dB). In the "audiovisual party," the talker's face was visible, whereas in the "audio-only party," no visual cues were provided. In each environment, hearing aid benefit was measured in terms of the difference between speech intelligibility scores obtained in aided and unaided listening conditions. After 10 weeks of regular hearing aid use, benefit was noted to have increased substantially for the audio-only party environment but not for the audiovisual party environment. In reporting this study (Cox and Alexander, 1992), the effect in which benefit increased over time was dubbed "maturation of benefit." In the present work, we refer to the effect as "acclimatization of benefit" in order to promote the use of standard terminology. The term acclimatization was introduced by Gatehouse in reporting a similar change in hearing aid benefit over time (Gatehouse, 1992); others have subsequently adopted this term.

It was surprising to note that benefit acclimatization occurred in the party setting only when no visual cues were provided. When the listener could clearly see the talker's face, benefit in the noisy setting did not improve over time. This led to the hypothesis that an important aspect of benefit acclimatization in noisy listening situations involves learning to take advantage of newly provided high-frequency auditory cues that are redundant with cues that are often available when the face is clearly seen. This would suggest that (1) the listener's ability to identify high-frequency speech cues such as place of articulation, using the auditory mode only, would increase during the first few months that the hearing aid is worn (assuming that amplification has actually increased the audibility of the high-frequency region); and (2) because place of articulation cues are readily seen on the talker's face (Walden et al, 1977), this improvement cannot be observed when visual cues are available.

To complicate matters, somewhat conflicting results on related topics were recently published by Gatehouse (1993), who refered to the effect as "perceptual acclimatization," and by Bentler et al (1993), who referred to a "training effect." Gatehouse (1992, 1993) studied 36 experienced hearing aid users who had been fitted with amplification having substantially less gain than the National Acoustics Laboratories' (NAL) recommendation (Byrne and Dillon, 1986) in the frequency region above 2.0 kHz. These individuals were refitted with new instruments that closely matched the NAL prescription through 4.0 kHz. They were then followed with speech intelligibility testing for 16 weeks. Results indicated that the new fitting steadily gained over the old one, ultimately producing a small but significant 4 to 5 percent improvement in aided monosyllabic word score.

Bentler et al (1993) studied a group of 65 experienced and novice hearing aid users over a period of 12 months following a new hearing aid fitting. She reported no significant changes in aided intelligibility scores over either the 12-month period or the initial 3-month period that corresponded to the study of Gatehouse (1992, 1993). Note, however, that there was a difference in insertion gain provided to subjects in the Bentler et al (1993) and Gatehouse (1992, 1993) studies: Gatehouse's fittings provided a close fit to the NAL prescription through 4.0 kHz, whereas the instruments used by Bentler et al (1993) allowed a close match to the NAL prescription only up to 2.0 kHz, with substantial underfit at higher frequencies. If our hypothesis about the acclimatization effect being due primarily to a learned use of high-frequency cues is correct, the difference in acclimatization between these two studies would be expected. However, there were other differences between the studies that might also explain the differing outcomes. These included different processing strategies (linear and compression), differences in previous amplification experience, and different volume control adjustments for the aided testing.

Our own work combined with that of Gatehouse (1992, 1993) and Bentler et al (1993) raised several questions that impact both research with hearing aids and their real-world applications. Most basic of all is the question of whether hearing aid benefit in noisy situations can be expected to improve from the level achieved at the time of fitting. If so, how much improvement occurs? The studies suggest that the average magnitude of the effect might be on the order of about 5 percent under typical conditions, which could result in its being mainly of academic interest. Further, we need to know whether the acclimatization effect is the norm or the exception. When Cox and Alexander's (1992) subjects were examined individually, only half (four of eight) of the novice users and three-fourths (three of four) of the experienced users actually showed improvement over time, suggesting that, although the trend towards improved benefit is statistically significant on a group basis, not all hearing aid wearers participate in this effect.

There are also practical concerns about the length of wearing time that might be necessary before meaningful measurements of hearing aid benefit can be obtained. To optimize satisfaction and success with hearing aid fittings, it is desirable to be able to estimate the amount of benefit that the user might expect from a particular hearing aid in the situations that are of most everyday concern. This idea has often prompted clinicians to measure benefit in noise as a part of the fitting process. However, if benefit in noisy situations improves over time with regular hearing aid use, there might be little predictive value in measuring it when the hearing aid is first fitted.

On the other hand, in clinical practice, there are limits in the time available for decision making. Thus, it is impractical to postpone benefit measurements for very long. Further, if improvement over time is consistent across subjects, it might still be possible to predict long-term benefit based on benefit measured at an early stage in the fitting process. Thus, we need to determine whether the acclimatization effect is essentially the same in all or most subjects or, if not, whether it is possible to discern in advance which individuals will experience significant growth of benefit with increased wear time.

This paper reports on a study that attempted to more clearly delineate the elements of benefit acclimatization for elderly hearing aid users in typical noisy listening environments. The research questions were as follows:

1. What is the magnitude of benefit acclimatization for new hearing aid users?
2. Are the acclimatization effects impacted by typical variations in the amount of insertion gain provided in the frequency region above 3.0 kHz?
3. Is acclimatization observable in some speech features and not others, and, if so, is the pattern consistent with improved use of high-frequency cues over time?
4. Do all individual users experience improved performance over time?
5. Is the presence or absence of benefit acclimatization related to success in hearing aid use?
6. If not all users exhibit benefit acclimatization, can we determine in advance which individuals will experience a sizable acclimatization effect?
7. Do acclimatization effects continue beyond 3 months of regular hearing aid use?

METHOD

Subjects

Cox and Alexander (1992) noted a significant acclimatization effect for both novice hearing aid users and experienced users fitted with a new hearing aid. However, the absolute amount of both benefit and maturation was different for the two groups, with the experienced hearing aid users exhibiting more benefit acclimatization, on average, than the novice users. In the present study, only nonusers of hearing aids were recruited as subjects because they are the group in which the outcome of a hearing aid fitting is most uncertain and, therefore, the group for which predictive methods are most urgently needed.

There were 22 subjects, 11 male and 11 female. Their mean age was 72 years (age range was 60 to 82). All had bilateral sensorineural hearing loss. Etiologies were judged to be either presbyacusis or presbyacusis with noise exposure. Twenty-one subjects had essentially symmetric hearing losses (three-frequency pure-tone averages [PTAs] within 15 dB bilaterally). One subject had a 50-dB difference in PTA between ears. Hearing aids were fitted to the better ear or, if there was no sensitivity difference, to the preferred ear.

Six subjects had tried a hearing aid without much success at some time in the past. Four of these had decided that they did not need amplification at the time. The other two reported noise and discomfort, respectively, as the reasons for rejection of their previous fittings. None was currently a hearing aid user or had used a hearing aid in the recent past.

In Figure 1, the test ear audiograms of individual subjects are depicted with solid lines.

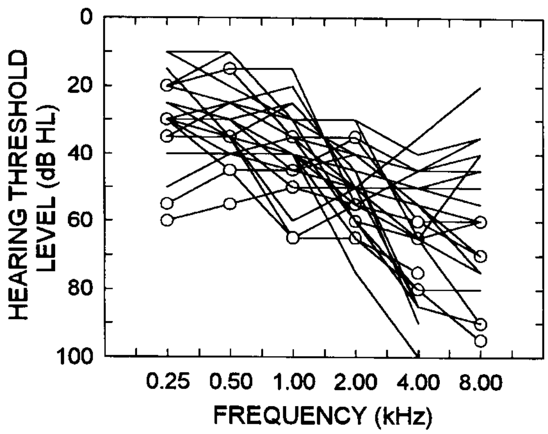

Figure 1 Test ear audiograms for 22 experimental subjects (solid lines) and 5 control subjects (lines with circles).

Threshold configurations tended to be sloping from mild to moderate or moderately severe. In addition, five control subjects were used to explore any change in intelligibility scores over time due to increased familiarity with the intelligibility tests themselves. These were all experienced regular hearing aid users. Test ear audiograms for these subjects are depicted in Figure 1 with solid lines and circles. The average hearing loss for the control subjects was a bit more severe than that of the experimental subjects. They ranged in age from 68 to 82 with a mean of 72 years.

Hearing Aid Fittings

Each of the 22 experimental subjects was fitted unilaterally with one of three different models of hearing aids. By prior agreement, these hearing aids were loaned to the subjects for the duration of the study and were returned to the research laboratory at the end of the study.

Three instrument models were used to permit more generalizable conclusions and to give some consistent variations in high-frequency gain. The three hearing aids were the 3M (8200), Maico-Bernafon Phox (P4), and Widex Quattro (Q8). All are mild-to-moderate gain behind-the-ear (BTE) programmable instruments. The goal was to fit all instruments as linear processors (those familiar with the 3M instrument will realize that linear processing can only be approximated in some cases because of the interactions among program parameters). To the extent possible, subjects were grouped into matched triads based on their audiograms and each hearing aid model was allocated to one member of the triad. Some subjects began the study but did not finish for various reasons and not all subjects had audiograms that could be matched with those of other subjects. The distribution of models among the subjects who finished the study was 3M = 8, Phox = 8, and Widex = 6.

Frequency response targets were generated using the NAL procedure (Byrne and Dillon, 1986) and match to the target was verified with insertion gain measurements. SSPL90 targets were generated using version 3.1 of the Memphis State University (MSU) procedure (Cox, 1988) and documented with 2-cc coupler measurements. The closeness of the match of fitted to target gain levels is discussed below.

All experimental subjects received a structured postfitting management program for at least 3 weeks after the hearing aid fitting. This program encompassed conventional informational counselling, assigned home exercises, and a gradual build-up of daily wearing time for the amplification device. Before entering the experiment, all subjects agreed to eventually wear the fitted hearing aid for at least 4 hours daily during the study. Actual reported wear times averaged 5 hours per day for the first week and 8 or more hours per day from the third week through the twelfth week.

Speech Intelligibility Tests

Aided and unaided speech intelligibility were quantified using the Connected Speech Test, or CST (Cox et al, 1988), and the four segmental subtests of the Speech Pattern Contrast (SPAC) Test (Boothroyd, 1985). The CST is designed to simulate everyday speech to the extent possible. It was used in this study to provide an estimate of speech communication ability in daily life situations. The SPAC test is an analytic test that quantifies the ability to perceive certain speech features. It was used in this study with the goal of delineating the elements of benefit acclimatization by exploring changes in identification of individual speech features.

The CST consists of 10-sentence speech passages about common topics, produced by a female talker of average intelligibility. The competing sound is a six-talker babble. Each passage contains 25 scoring words. Before presentation of a passage, the listener is informed of the passage topic. The passage is then presented one sentence at a time. After each sentence, playback is paused while the subject repeats the sentence or as much of it as he/she understood or could guess. In this investigation, 12 passages (300 scoring words) were used per score and intelligibility was measured under audio-only conditions (i.e., no visual cues).

In the SPAC test, the target word is embedded in one of several short sentences. The subject is required to select the target word from a closed set of four words that differ on only two speech features. The test encompasses eight speech features altogether: vowel height and place, word-initial and word-final continuance, word-initial and word-final place of consonant articulation, and word-initial and word-final voicing. The contrasts are tested in pairs. For example, in the test sentence "Choose the word *did* next," the contrasts under scrutiny are initial consonant place (ICP) and final consonant place (FCP). The test item is "did" and the four alternative responses are "did," "big," "bid," and "dig." A response of "did" is correct for both contrasts. Responses of "bid" and "dig" are correct for only FCP and ICP, respectively. The response "big" is wrong for both contrasts.

Each form of the SPAC test includes 48 items with 12 test items devoted to each pair of contrasts. The test produces nine scores, one for each contrast and a composite score (the average of all contrasts). In this investigation, two forms were used, and the results averaged, for each test condition. To control the effects of individual talker intelligibility, the speech material for the SPAC test was recorded by the same talker who produced the speech for the CST. Details of the test recordings may be found in Cox et al (1987).

The CST and SPAC tests both are scored in terms of the percent correct responses. These scores were transformed into rationalized arcsine units, or raus (Studebaker, 1985), to minimize the relationship between performance and variability that is seen with percentage scoring. Within the range of about 12 to 88, raus correspond fairly closely to the analogous percentages.

Procedures

All intelligibility testing used the monaurally aided ear only. Control subjects were tested using their preferred ear. The nontest ear was plugged using a compressible foam earplug. The location of the subject's head in the sound field was controlled using a headrest and visually monitored. Calibration levels for speech and babble were measured at the listener's position in the unoccupied sound field. For both CST and SPAC tests, the target speech was delivered at a level of 63 dB Leq (equivalent continuous level). The competing multitalker babble was delivered at one of two SBRs chosen to be similar to those encountered in many everyday social events. Fourteen subjects listened at an SBR of 1 dB and eight listened at an SBR of 3 dB.

After the hearing aid fitting and prior to the first set of intelligibility tests, a preferred listening level (PLL) for amplified speech was established for the subject. The methodology for determining the PLL was described by Cox and Alexander (1994). Briefly, four combinations of speech and babble levels were presented in random order. For each combination, the subject adjusted the hearing aid's gain to select the level that they would choose in everyday listening. After this adjustment, preferred amplified speech levels were measured in the ear canal in 14 ⅓-octave band levels from 250 through 5000 Hz. The mean PLL was determined in ⅓-octave band levels by averaging the four sets of measurements. For all subsequent intelligibility testing in aided conditions, the hearing aid's volume control was adjusted to produce this amplified speech level (the mean PLL) in the ear canal.

CST testing was performed in a $1.9 \times 1.8 \times 1.9$ meter audiometric test room lined with sound-absorbing foam. The target speech was presented from a small loudspeaker (Realistic Minimus 7) located 1.2 meters in front of the subject. The multitalker babble was split and delivered from four identical small loudspeakers mounted in the corners around the listener at azimuths of 45, 135, 225, and 315 degrees. The frequency response of the reproduction system was essentially flat from 150 Hz to at least 13 kHz. SPAC testing was performed in a $1.5 \times 2.2 \times 2.0$ meter audiometric test room. Both target speech and competing babble were presented from a small loudspeaker (Realistic Minimus 7) located 1.2 metre in front of the subject.

The first set of intelligibility measurements from both CST and SPAC tests was obtained when the hearing aid was first fitted and before it was used outside the laboratory. Additional SPAC tests were run at 3-week intervals after the fitting, including the third, sixth, ninth, and twelfth weeks. Final benefit testing with the CST occurred after 12 weeks of hearing aid use.

RESULTS AND DISCUSSION

To address the first three research questions, we considered the results for the group as a whole.

1. *What is the magnitude of benefit acclimatization for new hearing aid users?*

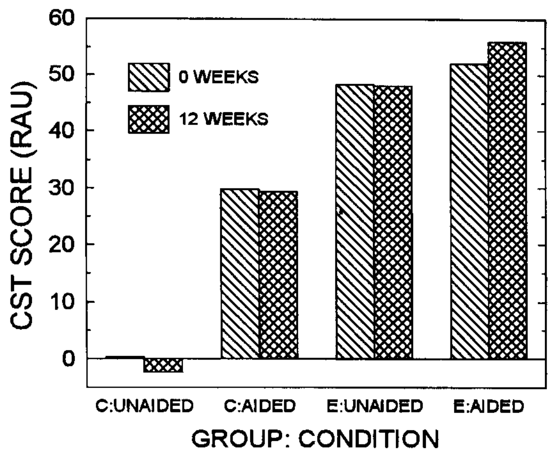

Figure 2 Mean aided and unaided scores for the CST on the day of hearing aid fitting and after 12 weeks of regular hearing aid use. C = control group, E = experimental group.

Figure 2 depicts mean aided and unaided CST scores for the control and experimental groups measured at 0-weeks and 12-weeks post-fitting. It is of interest to note that both unaided and aided performances for the control group were substantially poorer than those for the experimental subjects. This issue is addressed in more detail later.

To determine whether there was a significant change in scores over time, data for the experimental group were entered into a repeated measures analysis of variance (ANOVA) with two variables: session (0 weeks and 12 weeks) and listening condition (aided and unaided). For the experimental subjects, results indicated that the listening condition × session interaction was significant ($F[1, 21] = 5.68$, $p < .05$). A Student-Newman-Keuls post hoc test ($\alpha = .05$) revealed that, although there was no difference between the 0-week and 12-week unaided scores, the 12-week aided scores were higher than the 0-week aided scores. Inspection of the mean unaided and aided data for the control subjects reveals that there was no evidence of improvement in scores over time for these individuals. This observation was supported by statistical analyses of these data.

The fact that there were no significant changes over time in unaided scores for either group or in aided scores for the control group bolsters the assertion that subjects did not learn to perform better on the CST during this study. Thus, the improvement in aided performance for the experimental subjects was presumably due to the benefit acclimatization effect. Although the effect was statistically significant, its absolute magnitude was only about 4 to 5 percent on average. In other words, the mean benefit in noise increased from about 4 percent on the day the hearing aid was fitted to about 8 percent after 12 weeks of regular use. This is similar to the absolute magnitude of improvement reported by Gatehouse (1993) after 16 weeks.

Thus, the results of this study, suggesting a small but significant change in benefit over time, replicated our previous results and those of Gatehouse (1992, 1993) but tended to be at variance with those of Bentler et al (1993). However, the different outcomes of these studies might largely be attributable to the power of the experiments to detect the acclimatization effect. The power is determined by the number of subjects who complete the study, the variability in performance across subjects, and the actual size of the effect under study. To illustrate, a retrospective analysis of the present experiment revealed that the power of the experiment to detect a difference of 4 to 5 percent was about .6, or 60 percent. A power of .6 indicates that, in 4 of 10 similar studies, the effect would not be statistically significant effect at the $\alpha = .05$ level.

2. *Are the acclimatization effects impacted by typical variations in the amount of insertion gain provided in the frequency region above 3.0 kHz?*

Small but consistent differences in high-frequency insertion gain can often be seen across different hearing aids even after the most careful adjustments and modifications. Figure 3

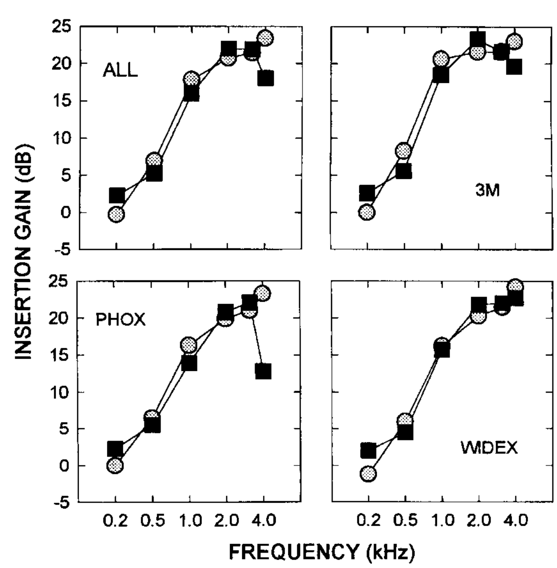

Figure 3 Mean prescribed (shaded circles) and fitted (solid squares) insertion gains.

illustrates mean prescribed (shaded circles) and fitted (solid squares) insertion gains for the instruments used in this investigation. The upper left panel shows all subjects combined. The upper right panel depicts the eight subjects fitted with the 3M instrument. The lower left panel gives data for the eight subjects fitted with the Phox instrument. The lower right panel shows the six subjects fitted with the Widex instrument. All three instruments allowed a close match to the target through 3.0 kHz but there were differences at 4.0 kHz and presumably above this frequency. The closest match to 4.0 kHz insertion gain target was obtained with the Widex, followed by the 3M and then the Phox.

The consistent differences among the instruments allowed us to evaluate the hypothesis that subjects showing the greatest acclimatization of benefit would be those whose hearing aids provided more improvement in audibility for high-frequency speech cues. However, to allow valid comparisons of effects across hearing aids, it was necessary to control for differences in hearing loss across subjects. As noted earlier, we addressed this by allocating subjects to matched triads on the basis of their audiograms and fitting one of each triad with each hearing aid.

Six matched triads (18 subjects) completed the study. Figure 4 depicts mean ear canal measurements of the change in audibility provided by the 18 hearing aids in low- (0.25–0.63 kHz), mid-(0.8–1.6 kHz), and high- (2.0–5.0 kHz) frequency regions. These data were obtained after gain adjustment to each subject's PLL. The results are consistent with Figure 3 in suggesting that the Widex instrument provided more

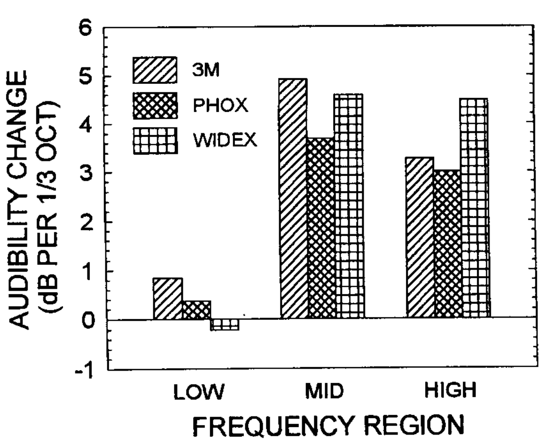

Figure 4 Mean change in audibility provided by each of the three hearing aids after volume control adjustment to the wearer's preferred listening level.

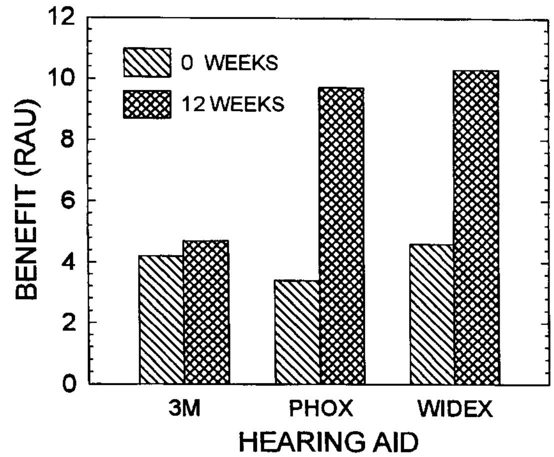

Figure 5 Mean benefit (aided minus unaided scores) obtained for the CST on the day of fitting and after 12 weeks of regular hearing aid use. Data are given separately for each hearing aid.

improvement in high-frequency audibility than the other two. Thus, based on the data in Figures 3 and 4, we hypothesized that the subjects fitted with the Widex instrument would show more improvement in benefit over time than those fitted with the other two instruments.

Figure 5 illustrates the benefit changes observed over time for these 18 subjects, each wearing one of the three hearing aids. At week 0, the initial fitting, there were only small mean differences in benefit across the hearing aids, amounting to about 1 percent. After 12 weeks of hearing aid use, the differences across instruments were quite a bit greater, with relatively large improvements seen, on average, for the Widex and Phox fittings but very little mean change for the 3M fittings. Although this outcome does suggest a difference in acclimatization effect across hearing aids, it does not substantiate our hypothesis regarding the role of high-frequency audibility in this effect. Furthermore, at least with this relatively small number of subjects, the differences in benefit acclimatization across hearing aids were not statistically significant ($p > .1$).

Thus, we were not able to demonstrate a difference in acclimatization effects related to typical variations in high-frequency gain when all instruments were fitted to match the NAL prescription through 3.0 kHz and variations in gain were limited to higher frequencies. Nevertheless, we should note that, because of the relatively small number of subjects in each triad, the statistical power of the analysis was relatively low—about 44 percent. In other words, even if the between-hearing-aid differences in Figure 5 are illustrative of genuine differences (rather than measurement errors), the likelihood of these effects being statistically detected was not very great.

It also should be noted that the null outcome of this analysis does not contradict the results reported by Gatehouse (1993), described above. The differences between amplification conditions compared by Gatehouse were much greater than those used in this study, and they encompassed a wider frequency region. Essentially, the Gatehouse study indicates that careful matching of the NAL gain recommendation through 4.0 kHz will ultimately produce a better result than substantially underfitting the 2.0- to 4.0-kHz region. The results of the present study suggest that, if the NAL recommendations are carefully matched through 3.0 kHz, relatively small deviations from the recommendations at higher frequencies might not have serious consequences.

3. *Is acclimatization observable in intelligibility for some speech features and not others, and, if so, is the pattern consistent with improved use of high-frequency cues over time?*

This issue was examined using the results of the SPAC test. The design of this test should allow repeated administrations with small likelihood of learning effects. In addition to a composite score, the SPAC provides separate scores for eight phonetic features: vowel height (VHT), vowel place (VPL), initial consonant voicing (ICV), final consonant voicing (FCV), initial consonant continuance (ICC), final consonant continuance (FCC), initial consonant place (ICP), and final consonant place (FCP). We assumed that features reflecting discriminability of voicing and vowel height and place would rely mainly on low- and mid-frequency audibility, whereas those reflecting discriminability of stop-versus-fricative production and place of articulation would be largely dependent on the audibility of relatively high-frequency speech energy. Thus, we hypothesized that more benefit acclimatization would be seen for ICC, FCC, ICP, and FCP than for VPL, VHT, ICV, and FCV.

Figure 6 depicts composite SPAC scores for unaided and aided listening at postfitting weeks 0, 3, 6, 9, and 12. Data are given for both control and experimental subjects. As seen with the CST scores, the performance of the control subjects was substantially poorer than that of the experimental subjects. In addition, note that the aided score for the controls decreased substantially at week 12 compared with the trend seen in previous weeks. Although this was not a statistically significant change, it roused suspicion about the data obtained in this final session: we had no reason to expect this type of result to occur and every reason to expect continued consistent performance from these subjects. These results might indicate that we were not successful in maintaining subject vigilance on the SPAC test in the final session. We have seen this sort of effect in other studies that

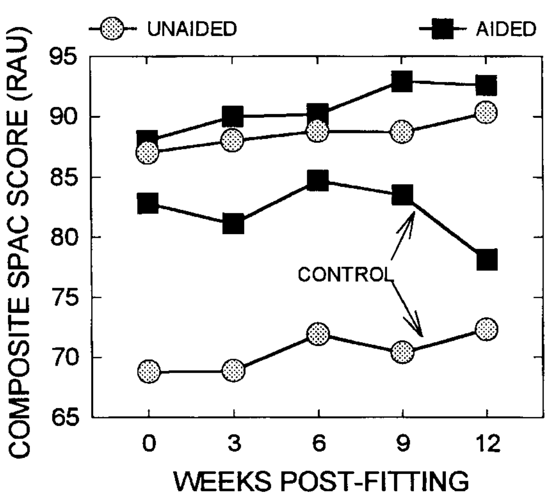

Figure 6 Composite scores for the SPAC test, measured on the day of fitting and after 3, 6, 9, and 12 weeks of regular hearing aid use. Data are given separately for experimental and control groups.

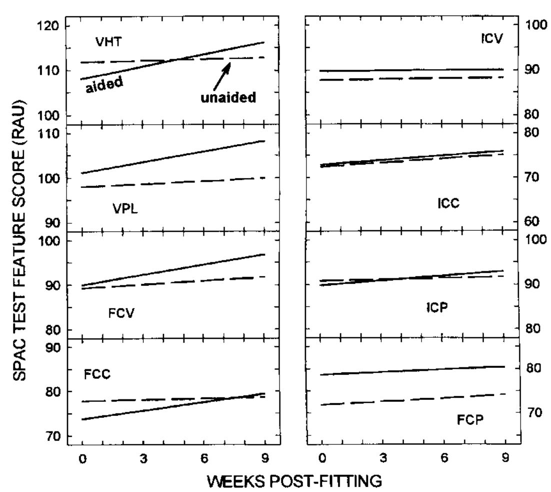

Figure 7 Mean results for the experimental subjects on the SPAC test over the first 9 weeks of hearing aid use. The lines are first-order regression lines on scores obtained in unaided (dashed) and aided (solid) conditions. Features on the left produced a pattern of results consistent with an acclimatization effect. Features on the right did not.

involve numerous repetitions of a tedious and difficult task. Subjects tend to "let down" on the final session and this produces anomalous results. Based on this suspicion, SPAC test results are reported from weeks 0 through 9 only. Actually, this had little effect on the outcomes of the study.

To examine changes in SPAC composite scores over time, separate ANOVAs were performed for control subjects unaided, control subjects aided, experimental subjects unaided, and experimental subjects aided. Each analysis included variables for postfitting week (0, 3, 6, and 9) and speech features (eight contrasts). Results for the control subjects in both aided and unaided listening conditions indicated no significant differences in overall scores across the four tests. This is consistent with the expectation that the SPAC test can be given repeatedly without producing much learning effect (in this figure and in Figure 7, there is a slight upward trend in the data for unaided conditions, suggesting that a very small amount of learning does occur for this test).

For the experimental subjects, there were no significant differences across sessions for unaided listening but there was a significant change across sessions for aided listening ($F[3, 60] = 5.57$, $p < .01$). A Student-Newman-Keuls post hoc test ($\alpha = .05$) revealed that the scores at 9 weeks postfitting were better than those obtained at 0, 3, and 6 weeks. This result was consistent with the existence of an acclimatization effect. In addition, the time course of improved performance between 6 and 9 weeks postfitting is roughly consistent with the report by Gatehouse (1992) that benefit improvements began to be seen after 4 to 6 weeks postfitting.

Having established that composite scores for the SPAC test did improve over time as anticipated, the next step was to evaluate the improvements for different speech features by considering the interaction between feature scores and test sessions. However, the ANOVA results indicated that the session × feature interaction was not significant, revealing that different features did not show a clearly different pattern of change over time. Nevertheless, because we hypothesized *a priori* that some features would show more improvement over time than others, we examined the patterns of scores for each feature.

Figure 7 illustrates the results for individual features and allows us to assess whether the trends in the data supported our hypothesis, despite the lack of a statistically significant outcome. The lines are first-order regression lines depicting the pattern of scores over time in unaided (dashed) and aided (solid) conditions. If the data suggest an acclimatization effect, we expect the slope showing the growth of the aided scores over time to be greater than that of the unaided scores. If there is no acclimatization over time, both aided and unaided scores should produce lines with about the same slope. Examination revealed that there were four features with a pattern suggesting an acclimatization effect and four features for which the slopes of aided and unaided lines were about the same. The four features that suggest benefit acclimatization are shown on the left side of Figure 7 and the right side shows data for the four features that did not seem to suggest acclimatization over time.

The question of interest was whether the features that seem associated with acclimatization in the experimental group were ones that are expected to rely on high-frequency auditory information. The answer appears to be no. The features on the left side of the figure are VHT, VPL, FCV, and FCC. Of the four, only FCC would appear to rely largely on high-frequency information.

In summary, the results of the SPAC test supported the presence of an acclimatization effect but did not point to improved use of high-frequency information as the basis for the effect.

The next three research questions required evaluation of the individual data.

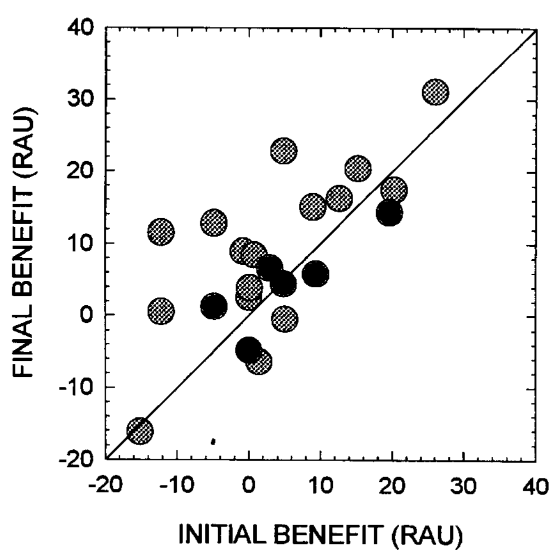

Figure 8 Initial and final benefit on the CST for each experimental subject.

4. *Do all novice users experience improved performance over time?*

Figure 8 illustrates initial benefit, measured at 0 weeks, and final benefit, measured at 12 weeks, for each subject. The six subjects who had used hearing aids without success in the past are shown with darker symbols. These subjects did not produce results that seemed unusual in any way. If initial and final benefit were equal, we would see all of the data falling on the diagonal line. If final benefit is greater than initial benefit, the data points will fall above the diagonal line. The figure shows more points above the diagonal than below it. This is the basis for the statistical effect. However, most individuals did not show a large acclimatization effect, as evidenced by the fact that most of the data points are fairly close to the diagonal. The fact that some data points are actually below the diagonal implies that some subjects did not experience improved benefit in noise over time.

5. *Is the presence or absence of benefit acclimatization related to success in hearing aid use?*

It seemed reasonable to ask whether individuals whose benefit improves during the first few months of hearing aid use are more likely to be positively inclined towards amplification and possibly more successful hearing aid wearers. Operationally, a positive inclination towards amplification was defined as either purchasing a hearing aid after the study or making definite plans to purchase one when it became financially feasible. By this definition, 13 subjects were positively inclined towards amplification at the end of the 12-week study. These were called the YES group. The other nine subjects were called the NO group.

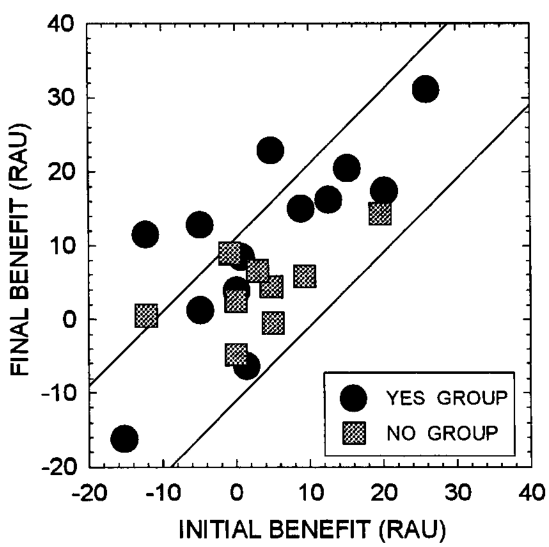

Figure 9 Data points give initial and final benefit on the CST for each experimental subject. Diagonal lines show the boundaries of the 95 percent critical difference for benefit scores.

In Figure 9, the two diagonal lines show the boundaries of the 95 percent critical difference for benefit scores. The data points depict initial and final benefit scores for each individual in the YES group and the NO group. Data points that fall between the diagonal lines represent subjects whose initial and final benefit scores, when considered alone, could not confidently be judged to be truly different because the amount of difference has a fairly high probability of occurring due to measurement error.

When we consider the data this way, only four individuals showed clear evidence of significant acclimatization over time, and one of them falls only slightly above the upper boundary of the nonsignificant region. Of these four, three were in the YES group and one was in the NO group. In addition, the 18 individuals who did not show significant acclimatization over time were about evenly split between YESes and NOs. This outcome did not suggest that growth in benefit over time is an important determinant of hearing aid success.

In fact, we come closer to separating the YESes and NOs using a simple cut-off value: if benefit in noise after 3 months is at least 10 rau (similar to 10%), the individual tends to be positively inclined towards amplification. However, we should also note that, of the 13 persons who achieved less than 10 percent benefit in noise after 3 months, 5 were in the YES group anyway.

6. *If not all users exhibit acclimatization, can we determine in advance which individuals will experience a sizable acclimatization effect?*

Despite a significant group trend toward improvement in benefit over time, the magnitude of the improvement was quite small for most subjects. As we saw in Figure 9, there were actually only 3 of 22 individuals who clearly had a sizable acclimatization effect (the three YESes above the upper diagonal line). Although there were no obvious factors that separated these three individuals from the crowd, it was of interest to determine whether any more subtle characteristics of these subjects might provide a clue about the basis of the acclimatization effect.

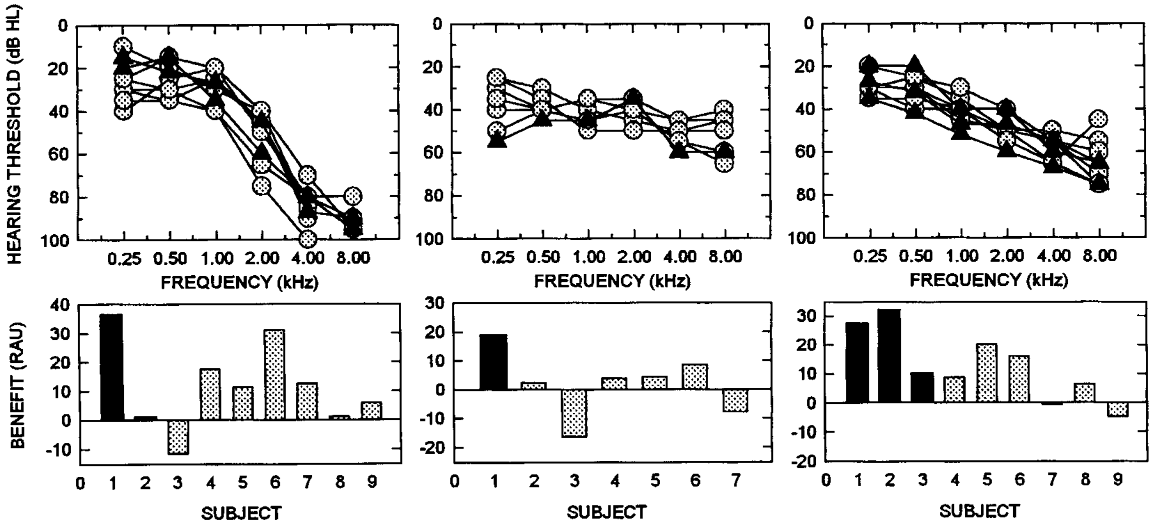

Figure 10 Audiograms (upper panel) and benefit scores (lower panel) for three groups of hearing aid wearers. Solid bars and triangles depict data for individuals who have worn hearing aids regularly for more than 1 year. Shaded bars and circles depict data for individuals who have worn hearing aids for only 3 months.

However, because of the small number of subjects involved, statistical tests were not likely to be useful. Thus, no conclusions could be drawn on this question. This issue should be addressed in future work.

7. *Do acclimatization effects continue beyond 3 months of regular hearing aid use?*

In the course of doing these and other studies, we have repeatedly noticed that successful, experienced hearing aid wearers often have two characteristics that separate them from novice wearers. First, their unaided speech intelligibility scores tend to be poorer. Second, they generally obtain more benefit from their hearing aids even after the novice subjects have had 3 months of hearing aid experience. In the present study, these trends can be observed by comparing results for experimental and control subjects in Figures 2, 6, and 7. One explanation for these differences could be that the experienced hearing aid wearers simply have more hearing loss

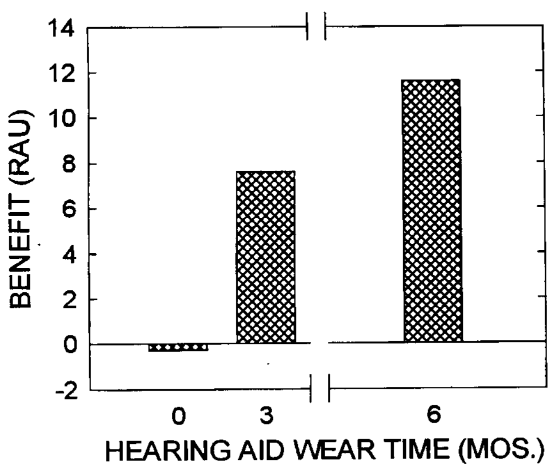

Figure 11 Mean benefit for seven subjects at the time of fitting a BTE instrument, after 3 months of experience with that instrument, and after 6 months of additional experience with an ITE instrument.

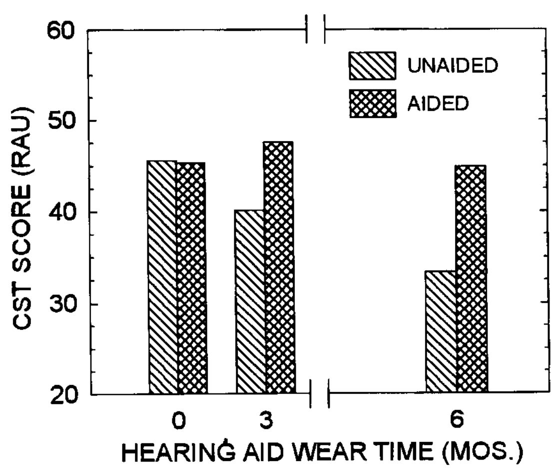

Figure 12 Mean aided and unaided intelligibility scores for seven subjects at the time of fitting a BTE instrument, after 3 months of experience with that instrument, and after 6 months of additional experience with an ITE instrument.

than the novice wearers. However, although hearing loss is an important variable in determining both unaided scores and benefit, it did not always seem to explain the differences observed.

To explore this matter, we re-examined recent data obtained in the laboratory in this and other investigations. Hearing aid wearers were allocated to groups based on their audiograms. Each group contained some individuals who had worn hearing aids regularly for only 3 months and at least one person who was classified as an experienced regular hearing aid wearer (daily use > 4.0 hours for at least 1 year). Three groups were generated. The benefit scores obtained by members of a group were compared to determine whether the experienced regular users seemed to obtain more benefit than the 3-month users. The results are illustrated in Figure 10. For each group, the upper graph shows audiograms and the lower graph shows hearing aid benefit for speech in noise.

Although the pattern is not fully consistent, there is a clear trend for experienced regular users to achieve more benefit than 3-month users with similar audiograms. Why is this? One possible explanation is that benefit acclimatization continues beyond the initial 3 months. To evaluate this possibility, we contacted our 22 subjects 6 to 12 months after they finished our study. We discovered that 12 of them were wearing amplification with some regularity at that time but only 7 met our definition of regular users by reporting hearing aid use in excess of 4 hours per day. All of these individuals had purchased in-the-ear (ITE) hearing aids after our investigation. They had worn them for an average of 6 months.

The seven individuals returned to the laboratory and benefit for speech in noise was tested with their new personal hearing aids. Figure 11 shows benefit measured in our study when the original BTE hearing aid was first fitted and after 3 months of use. In addition, benefit is reported for the new hearing aids after 6 months of use, on average. The figure indicates that this subgroup's benefit improved about 8 percent during the course of the original study and, after an additional 6 months of amplification, there was a sizable further improvement. These data support the conclusion that, at least for individuals who wear their hearing aid 4 or more hours daily, benefit may continue to improve beyond the 3-month point.

However, closer scrutiny of the data revealed a perplexing pattern illustrated in Figure 12. This figure depicts the aided and unaided scores that produced the benefit data in Figure 11. It shows that aided and unaided scores were essentially equal when the aids were fitted, producing zero benefit. After 3 months, benefit increased—partly because aided performance improved but also because unaided performance declined. After 6 more months of hearing aid use, the additional benefit was obtained entirely because unaided scores continued to decline. There was no further improvement in aided performance after the 3-month point. In fact, there was a small decrease in mean aided performance with the new hearing aid compared to the one used in our study.

The characteristics of the personal hearing aids were evaluated in an attempt to gain insight into the cause of the decrease in aided performance. Real-ear measurements indicated that audibility improvement at the preferred listening level was actually better for the new hearing aids than for the experimental hearing aids, especially in the high-frequency region. This probably can be attributed to the combination of ITE microphone placement effects and a slightly higher preferred listening level after several months of experience with amplified sound. However, examination of the maximum output levels revealed that, at all frequencies, but especially at high frequencies, the experimental hearing aids provided higher maximum outputs than the personal hearing aids. Thus, in this long-term follow-up, the subjects were using linear hearing aids with a combination of more gain and less maximum output than during our study. This would probably be sufficient to account for a reduced aided intelligibility performance.

In contrast, the observation of a persistent decline in unaided performance after the hearing aid fitting is not readily explainable. Because the long-term follow-up was not a part of the original study, it is possible that the subjects did not take it as seriously as the earlier test sessions and this resulted in overall poorer performance. We should keep in mind that the decline in unaided performance was seen in a select group of individuals and was not observable after 3 months in the full group of 22 subjects (see Fig. 2). On the other hand, a decline in unaided intelligibility scores following hearing aid fitting was also reported in four subjects by Gatehouse (1992), but only when subjects were listening to headphone-simulated unaided conditions, not during sound field listening. Gatehouse (1989) has proposed an acclimatization principle that might explain this type of finding. According to this principle, the ear becomes optimally attuned to extracting information from its customary acoustic input and tends to perform suboptimally for other input conditions. It should be noted that it is not reasonable to explain these observations in terms of the deprivation effect described by Silman et al (1984) because the aided ear has not been deprived of auditory stimulation. Further research is needed to explore the extent and pervasiveness of deterioration in unaided performance in hearing aid wearers.

SUMMARY AND IMPLICATIONS

This investigation was limited to elderly individuals with mild to moderate hearing loss who were inexperienced with amplification and fitted unilaterally with a hearing aid. The hearing aids were linear processors and provided an accurate match to the NAL prescription through 3.0 kHz. The results of observation of 22 subjects over the first 3 months of hearing aid use can be summarized as follows:

- Although growth in benefit for speech intelligibility in noise was statistically significant on a group basis, the absolute size of the average effect was quite small. This outcome suggests that, for most elderly hearing aid wearers, a reasonable approximation of the benefit to be obtained in noise could be measured on the day of fitting after, say, 15 to 30 minutes of practice using the new instrument for listening to speech in noise.
- Although there were some differences in the audibility improvement provided by the different hearing aids in the high-frequency region, there was no relationship between these differences and the improvement in benefit over time. This result suggests that, if the frequency gain prescription is closely matched through 3.0 kHz, typical variations in gain above that frequency might not have significant impact on any acclimatization effect.
- When all speech features were pooled into a composite score, a significant improvement in aided intelligibility occurred in the time interval between 6 and 9 weeks postfitting. This result could be valuable in counselling hearing aid wearers. They should expect to invest at least 6 weeks of daily practice with the new hearing aid before improvements beyond those seen on the first day can be expected.
- Recognition of speech features that rely on high-frequency cues did not improve over time more than that for other speech features. This suggests that the acclimatization effect is the result of a general refinement of abilities, not necessarily limited to any frequency region. However, it should be noted that the power of statistical tests that could be directed at this issue was somewhat limited, and continued assessment is indicated.
- Not all novice hearing aid wearers exhibited growth in benefit over time and it was not possible to conclude that a substantial acclimatization effect increased the likelihood of long-term success in hearing aid use. Some individuals showed improvement over time and others did not: improvement per se did not seem to influence the long-term success of the hearing aid fitting. A stronger predictor of success was the magnitude of benefit in noise after the adaptation period, regardless of whether this benefit was seen on the first day or only after considerable practice.
- Three individuals did exhibit sizable acclimatization of benefit in the first 3 months. There was nothing superficially remarkable about these subjects and the numbers were too small for statistical testing of potentially related variables.

For the seven individuals who were followed beyond 3 months, the results support the following conclusions:

- It appears that individuals who become the types of hearing aid wearers that clinicians often judge to be successful may experience a continuing growth of hearing aid benefit over a long period of time. However, a large part of this growth may be due to a progressive decline in speech recognition ability in a normally aided ear when listening to unamplified speech in noise. This observation is both intriguing and troubling. Patients contemplating their first hearing aid sometimes express concern that they will "become dependent" on amplification. Clinicians have traditionally given little credence to this idea, yet our findings on this small subgroup suggest that there may be some basis for this concern. This phenomenon demands further study to determine whether it is robust and, if so, whether certain types of individuals are more at risk for a decline in unaided performance.

- A decline in unaided intelligibility was not seen during the first 3 months of hearing aid use for the entire group of 22 subjects, many of whom did not ultimately become regular hearing aid wearers.
- We cannot determine from these data whether there is a continuing growth in aided speech recognition ability over a long period because aided conditions changed during the course of our observations. Data are needed that describe changes in both aided and unaided performance for a fixed amplification system over a period of at least 1 year postfitting.

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REFERENCES

Bentler RA, Niebuhr DP, Getta JP, Anderson CV. (1993). Longitudinal study of hearing aid effectiveness I: objective measures. *J Speech Hear Res* 36:808–819.

Boothroyd A. (1985). Evaluation of speech production in the hearing impaired: some benefits of forced-choice testing. *J Speech Hear Res* 28:185–196.

Byrne D, Dillon H. (1986). The National Acoustics Laboratories' (NAL) new procedure for selecting the gain and frequency response of a hearing aid. *Ear Hear* 7:257–265.

Cox RM. (1988). The MSU hearing instrument prescription procedure version 3.0. *Hear Instr* 39(1):6–10.

Cox RM, Alexander GC. (1992). Maturation of hearing aid benefit: objective and subjective measurements. *Ear Hear* 13:131–141.

Cox RM, Alexander GC. (1994). Prediction of hearing aid benefit: the role of preferred listening levels. *Ear Hear* 15:22–29.

Cox RM, Alexander GC, Gilmore C. (1987). Intelligibility of average talkers in typical listening environments. *J Acoust Soc Am* 81:1598–1608.

Cox RM, Alexander GC, Gilmore C, Pusakulich KM. (1988). Use of the Connected Speech Test (CST) with hearing-impaired listeners. *Ear Hear* 9:198–207.

Gatehouse S. (1989). Apparent auditory deprivation effects of late onset: the role of presentation level. *J Acoust Soc Am* 86:2103–2106.

Gatehouse S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: evidence from monaural fitting of hearing aids. *J Acoust Soc Am* 92:1258–1268.

Gatehouse S. (1993). Role of perceptual acclimatization in the selection of frequency responses for hearing aids. *J Am Acad Audiol* 4:296–306.

Silman S, Gelfand SA, Silverman CA. (1984). Late onset auditory deprivation: effects of monaural versus binaural aids. *J Acoust Soc Am* 76:1357–1362.

Studebaker GA. (1985). A "rationalized" arcsine transform. *J Speech Hear Res* 28:455–462.

Walden BE, Prosek R, Montgomery AA, Scherr CK, Jones CI. (1977). Effects of training on the visual recognition of consonants. *J Speech Hear Res* 20:130–145.