Maturation of Hearing Aid Benefit: Objective and Subjective Measurements

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ABSTRACT

The goals of this investigation were to determine whether hearing aid benefit improved significantly over the first 10 weeks of hearing aid use and whether time-related changes in benefit (if any) were affected by the type of benefit measurement (i.e., objective or subjective). A total of 17 hearing-impaired subjects participated, with different subjects completing different phases of the study. Benefit was measured soon after the hearing aid fitting and again after 10 weeks of adjustment to hearing aid use. Objective benefit data were determined using the Connected Speech Test. No significant changes in objective benefit were noted in noisy or reverberant listening environments when visual cues were available. However, in a low-noise setting and in a noisy setting without visual cues, improvements in objective benefit were seen over time. Subjective benefit data were derived from responses to the Profile of Hearing Aid Benefit. These data indicated significant benefit improvement over time in all five types of daily life situations assessed, although the improvement was small in reverberant and noisy environments. Significant, but modest, correlations were found between objective and subjective data for low-noise and reverberant listening environments. Comparison of experienced and novice hearing aid wearers suggested that although experienced wearers obtain more benefit than novice wearers, they evidence similar time-related changes in benefit during the first 10 weeks of new hearing aid use. (Ear Hear 13 3:131-141)

FOR MOST HEARING AID wearers, improved ability to understand speech in daily life is the major component of hearing aid benefit. As a result, speech understanding is often measured during hearing aid fitting and the results may be a major factor in determining amplification recommendations. For example, the difference between clinically measured aided and unaided speech understanding is often used to predict the hearing aid benefit that can be expected from the fitting. Nevertheless, there is a surprising paucity of data that establish the validity of this practice. In other words, we cannot assert with confidence that hearing aid benefit (aided versus unaided speech understanding) measured at the time the instrument is fitted can be used with accuracy to predict the daily life benefit that will ultimately be obtained from the fitting. Validated procedures are urgently needed for predicting long-term benefit on the day the hearing aid is fitted.

The most popular approach to quantification of long-term benefit of a hearing aid fitting uses a self-report questionnaire in which the experienced hearing aid wearer subjectively assesses the benefit provided by the instrument in daily life. Long-term subjective assessments of benefit have sometimes been compared with objective benefit measurements (i.e., speech understanding scores) that were acquired during the initial hearing aid fitting. This comparison reveals whether the early objective measures could be used to predict the long-term subjective data. Most of these studies have reported a negative outcome. That is, objective measures of speech understanding obtained during the hearing aid fitting were not found to be closely related to the long-term subjective benefit of the instrument (e.g., Haggard, Foster, & Iredale, 1981; Scherr, Schwartz, & Montgomery, 1983; Stroud & Hamill, 1989; Surr, Schuchman, & Montgomery, 1978)

A factor that complicates the prediction of long-term hearing aid benefit is the learning or adjustment process that follows the acquisition of a hearing aid. It is well established that most hearing aid wearers require at least several weeks of hearing aid use before they report that they are "adjusted" to the instrument (e.g., Berger & Hagberg, 1982; Kapteyn, 1977). This adjustment must be partly physical in that the user is learning to manipulate the instrument. However, it also may encompass a learning process during which speech understanding with the hearing aid is optimized. Barfod (1979) has utilized a speech perception model to propose an explanation for this optimization process. The model postulates a preliminary auditory analysis followed by a "recognition device." The preliminary auditory analysis converts the incoming acoustic signal into neural impulses. The recognition device matches these neural patterns with previously learned data to determine the spoken phonemes. Amplification, especially when it is frequency dependent, modifies the

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speech input and thus changes the output of the preliminary auditory analysis, producing new patterns. Any new recognition cues in the patterns must be learned by the recognition device before speech understanding can be optimized for amplified speech. The modification of the recognition device would require experience listening to amplified speech. The time required for the optimization process would vary both with the extent to which the new input signal supplies additional cues and with the adaptability of the hearing aid wearer. If, as suggested by Barfod (1979), recognition device optimization can be an important factor in hearing aid adjustment, it follows that aided speech understanding measured on the same day the hearing aid is fitted might underestimate the performance to be achieved after the adjustment process.

Overall, these considerations suggest that subjective or objective hearing aid benefit measured at or near the time of the hearing aid fitting cannot be used with confidence to predict either long-term subjective benefit or long-term objective benefit. Although this situation is not new, it is especially problematic in recent times because fitting procedures for contemporary high-technology hearing aids often rely on speech intelligibility comparisons at the time of fitting to determine signal processing characteristics, such as adaptive low-frequency gain, compression ratio, etc. In addition, the introduction of multimemory hearing aids has made it possible to fit instruments that have different performance characteristics for different environmental situations. Although no systematic approach to the selection of these environment-specific characteristics has been widely adopted, clinical speech understanding measurements in different, perhaps simulated, listening environments is an attractive option. These developments have considerably increased the pressure for data that address the predictive validity of clinical benefit measures that are obtained at or near the time of hearing aid fitting.

This article reports a study that was undertaken to document the maturation of subjective and objective hearing aid benefit over the first 10 weeks of hearing aid use, and to determine the relationship (if any) between them. Both objective and subjective measures of benefit were obtained for each of several typical listening environments. The research questions were: (1) Is benefit measured at or near the time of hearing aid fitting similar to, or predictive of, long-term benefit? (2) Is objectively measured benefit related to subjectively estimated benefit? (3) Are the answers to questions 1 and 2 related to the subjects' experience in hearing aid use?

METHOD

Listening Environments

Both theoretical considerations and the data of Walden, Demorest, and Hepler (1984) suggest that three basic listening environments can be defined. These place distinctly different demands on the listener and together represent a large proportion of everyday listening situations experienced by the typical hearing aid wearer. These three environments have also been used by us in other studies of hearing aid benefit (e.g., Cox & Alexander, 1991a). The three environments are designated A, B, and C. Environment A represents communication in a situation in which speech is at normal conversational level, visual cues are fully available, and background noise and reverberation are low. Examples of environment A include face to face conversation in a typical living room or quiet office. Environment B represents communication in a situation in which external environmental noise is low but speech cues are reduced because of reverberation, low speech intensity, or limited or absent visual cues. Examples of environment B include listening as an audience member to a lecture delivered in an unamplified classroom, communicating over a distance, and listening to someone whose face is not visible. Environment C represents communication in a situation where external environmental noise is relatively high, speech levels are somewhat raised, and visual cues are available. Examples of environment C include face to face communication at a social event with numerous people present, and communication with a clerk in a busy store. In the present study, both objective and subjective benefit measures were obtained for each of these three listening environments. In addition, objective measures were obtained in a listening environment typical of clinical audiometric evaluations in which no visual cues are available, designated environment CL.

Objective Benefit Measures

Hearing aid benefit was objectively quantified in terms of the difference between aided and unaided scores for the Connected Speech Test (CST). This test was developed as a vehicle for assessing intelligibility of conversationally produced everyday speech. Its recording and standardization have been fully described in previous publications (Cox, Alexander, & Gilmore, 1987; Cox, Alexander, Gilmore, & Pusakulich, 1988, 1989). Briefly, the talker for this audiovisually recorded test is a female who has been empirically determined to produce speech of average intelligibility. The competing message is a six-talker speech babble. The test is composed of 10-sentence passages about common topics. The passages are grouped into eight sets of six passages. All sets are essentially equal in intelligibility for normal hearing and most hearing-impaired listeners. In the present study, one set of six CST passages (150 scoring words) was used in each condition.

Before a passage is presented, the listener is shown a word describing the passage topic. A passage is presented one sentence at a time. After each sentence, both speech and babble are halted while the subject repeats the sentence or as much of it as he/she understood. Subjects are instructed to repeat every word exactly as heard. Each passage contains 25 scoring words. The test is scored in terms of the number of scoring words correctly repeated. Percent correct scores are transformed into rationalized arcsine units (rau) to minimize the relationship between mean score and variance (Studebaker, 1985). The rau scale extends from −123 to +123. Within the range from about 12 to 88, rau scores are close to the corresponding percentage scores.

In previous work (Cox & Alexander, 1991a), objective benefit measures have been acquired with subjects actually situated in real rooms typifying each listening environment. However, Cox, Alexander, and Rivera (1991) reported that these environments could be closely simulated in an audiometric test room with appropriate adjustments of signal to babble ratio (SBR) and reverberation time. Thus, in this study, Environments A, B, and C were simulated in a 1.9 × 1.8 × 1.9 m audiometric test room lined with sound-absorbing foam. Ambient noise in the test room was 53 dB (C)/19 dB (A). The environments were simulated by processing the CST target speech and multitalker babble using a two-channel electronic reverberator (Yamaha, Rev 5) and then presenting the processed speech and babble to subjects listening in the sound field. The target speech was presented from a small loudspeaker (Realistic Minimus 7) located 1.4 m 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°. Both speech and babble were presented at levels appropriate for the environment to be simulated, measured at the listener's position in the unobstructed sound field. The frequency response of the reproduction system was essentially flat from 150 Hz to at least 13 kHz.

In simulated environments A, B, and C, the data of Pearsons, Bennett, and Fidell (1977) were used to determine appropriate speech and background noise levels. The levels were those reported by Pearsons et al to be maintained by talkers and listeners in everyday environments to allow essentially complete intelligibility for conversations in that setting.

In environment A, the target speech level was 55 dBA L_{eq} (L_{eq} = equivalent continuous level) and the background noise was delivered at 48 dBA L_{eq}. In environment C, the target speech level was 64 dBA L_{eq} and the background noise was delivered at 62 dBA L_{eq}. In Environments A and C, the listener is assumed to be located well within the critical distance, thus, reverberation effects on the target signal are small. Because Cox, Alexander, and Rivera (1991) reported reverberation effects to be negligible in these two environments, no reverberation was used in the current study. Visual cues were provided by displaying the talker's head and shoulders on a 33 cm (diagonal) color monitor. This produced an image slightly less than life-sized and was consistent with a face to face listening situation.

In environment B, the target speech was delivered at a level of 63 dBA L_{eq} and the background noise was delivered at 55 dBA L_{eq}. In this environment, the reverberator was configured to simulate a listening location well outside the critical distance in a small auditorium with overall reverberation time (RT_{60}) of about 1 sec. Reverberation times as a function of frequency were as follows: 0.125 kHz = 1.14 sec, 0.25 kHz = 1.05 sec, 0.5 kHz = 1.09 sec, 1.0 kHz = 1.08 sec, 2.0 kHz = 1.02 sec, 4.0 kHz = 0.96 sec. The first four reflections occurred 20, 36, 48, and 54 msec after the direct sound and at levels of −1, −4.6, −3.9, and −11.3 dB, respectively, relative to the direct sound. Later reflections were dense and random and decayed gradually in a manner similar to real rooms. Visual cues were provided, as would be the case in a lecture or religious service. However, to simulate listening at a considerable distance, the image was displayed on a 13 cm (diagonal) color monitor screen.

In environment CL, simulating clinical testing, the target speech and competing babble were presented at the same levels as for environment C but without visual cues.

Subjective Benefit Measures

Hearing aid benefit was subjectively quantified using the Profile of Hearing Aid Benefit, or PHAB (Cox, Gilmore, & Alexander, 1991). This 66-item inventory assesses performance in a variety of everyday situations. Each item is a statement, such as "I have to ask people to repeat themselves

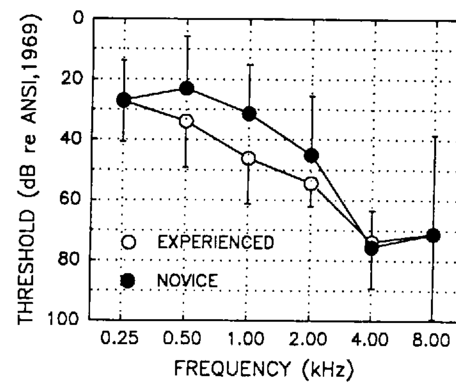

Figure 1. Composite audiograms of eight novice and nine experienced hearing aid users who participated. Error bars give 1 SD.

in one-on-one conversation in a quiet room." The respondent's task is to indicate the proportion of time that the statement is true, using a seven-point scale as follows: always (99%), almost always (87%), generally (75%), half the time (50%), occasionally (25%), seldom (12%), and never (1%). Each response choice includes both a descriptor and a percentage. Responses are scored in terms of the percentage. Each item is answered twice, once for "without my hearing aid" and again for "with my hearing aid." Hearing aid benefit is defined as the difference between the two responses.

The PHAB can be scored in terms of seven subscales or four scales. In the present study, scoring was accomplished using the subscales. The test items and details of subscale development may be found in Cox and Gilmore (1990). Briefly, the subscales are: Familiar Talkers (FT): seven items describing communication under relatively easy listening conditions with persons whose voices are known. Ease of Communication (EC): seven items describing the effort involved in communication under relatively easy listening conditions. Reverberation (RV): nine items describing speech understanding in moderately reverberant rooms. Reduced Cues (RC): nine items describing communication without visual cues or when intensity is low. Background Noise (BN): 16 items describing speech understanding in the presence of multitalker babble or other environmental competing noise. Aversiveness of Sounds (AV): 12 items describing negative reactions to environmental sounds. Distortion of Sounds (DS): six items describing the quality of voices and other sounds.

Subscales FT and EC are considered to represent everyday situations of the environment A type. Subscales RV and RC exemplify environment B listening situations. Environment C listening conditions are illustrated in subscale BN. Subscales AV and DS were not used in this study.

Subjects

Seventeen subjects completed various portions of the study, with 10 subjects completing all phases. Appendix A provides a summary of subjects completing each phase. Eight were new to hearing aid use, and the rest were experienced hearing aid wearers. Figure 1 illustrates composite audiograms of the novice and experienced subjects. Ages ranged from 52 to 81 with a mean of 67. Etiologies were mostly either noise-induced hearing loss or presbycusis. One subject reported Menière̊s disease. On average, those experienced with amplification wore their instruments about 8 hr/day and reported 6.5 yr of hearing aid use. On average, the new hearing aid users reported wearing their instruments about 4 hr/day during this study.

Procedures

Hearing Aid Fitting Twelve subjects, eight novice and four experienced, were fitted with new hearing aids (four additional experienced hearing aid users began the study, but were unable to complete any phase for a variety of health and personal reasons). The experienced subjects were successful hearing aid users who were obtaining replacements for worn-out instruments. Either the Memphis State University (Cox, 1988) or the National Acoustic Laboratories, (Byrne & Dillon, 1986) prescriptive method was used to generate frequency response goals. Real ear measurements of either functional gain or insertion gain were performed to assure reasonable compliance with the frequency/gain prescription. Maximum output (SSPL90) goals were determined using the Memphis State University procedure. Maximum output levels were set using 2-cc coupler measurements. Acoustically, the hearing aid fittings were representative of current practice.

Six subjects were fitted with in the ear hearing aids, and the rest received behind the ear instruments. Nine fittings were monaural and three were binaural. When the hearing aid(s) was issued, the subject was instructed in use and care of the instrument(s) and given instructions on procedures to facilitate adjustment to amplification. Most subjects were also seen clinically after about 2 weeks for a follow-up appointment, during which adjustment problems were explored and minor fitting modifications could be made.

Benefit Testing For subjects with newly fitted hearing aids, experimental data were collected in four sessions. In each condition of each session, testing was preceded by four to six practice passages. According to the report of Theodoridis and Schoeny (1990), this amount of practice should be sufficient to accommodate essentially all of the procedure learning effects associated with the CST. Session 1 occurred before the hearing aid fitting and was used for measurement of unaided speech understanding in environments A, B, C, and CL. Session 2 was held 1 to 3 days after the hearing aid fitting (nine subjects were tested within 1 day, the rest were instructed not to wear their new hearing aid(s) until after session 2). In this session, aided CST scores were obtained under the four listening conditions. For each condition, the difference between unaided (session 1) and aided (session 2) scores was the initial measure of objective hearing aid benefit.

Two weeks after session 2, a copy of the PHAB was mailed to the subject for completion. The responses constituted the initial measure of subjective hearing aid benefit.

Session 3 occurred 9 weeks after the hearing aid fitting. It was used to obtain a second set of measures of unaided speech understanding in each of the four conditions. Also, a second copy of the PHAB was given to the subject to be completed at home and returned during session 4. One week later, in session 4, aided speech understanding in each of the four listening conditions was measured for the final time. For each condition, the difference between the unaided (session 3) and aided (session 4) scores was the measure of long-term hearing aid benefit (the data reported by Berger & Hagberg, 1982, suggest that almost all subjects will report full adjustment to their new hearing aid after 10 weeks). The responses to the second PHAB constituted the long-term measure of subjective hearing aid benefit. Additionally, during sessions 3 and 4, subjects were asked to rate the similarity of the test environments A, B, and C to what they experienced in real life, using a 10-point scale in which 1 denoted low similarity and 10 represented high similarity.

Five additional experienced hearing aid wearers were not fitted with new hearing aids. All wore ITE hearing aids; there were two monaural and three binaural fittings. These subjects participated only in sessions 3 and 4, providing objective and subjective measures of long-term benefit.

Adjustment of hearing aid volume controls preceded all tests of aided speech understanding in sessions 2 and 4. While listening to CST passages presented at appropriate level and SBR for the to-be-tested environment, subjects were instructed to bracket their preferred listening level by setting the gain both too high and too low before choosing the final level. It was emphasized that they should choose the level that they would select in a real life setting. After volume control selection, further adjustment was permitted while the subject responded to practice CST passages. The final selected gain level was measured in a 2-cc coupler.

The order of administration of conditions was partially counterbalanced across subjects. Each subject received the same order of conditions in all sessions.

RESULTS

Objectively Measured Benefit

All 12 subjects fitted with new hearing aid (eight novice and four experienced) completed objective measurements of hearing aid benefit at the time of fitting (initial benefit) and after 10 weeks of hearing aid use (long-term benefit). The benefit data were subjected to analysis of variance (ANOVA) to determine whether benefit changed significantly during the 10 weeks of hearing aid use.

Initially, the group was divided into experienced and novice subjects to explore the effect of experience on benefit. A three-way, split-plot analysis (experience × listening environment × measurement time: initial versus long-term) revealed a significant effect of experience with the mean benefit for experienced subjects (8.8 rau) greater than the mean benefit (1.9 rau) for novice subjects [$F(1,10) = 5.45$, $p < 0.05$). However, none of the interactions with experience was significant, indicating that the pattern of benefit data was not different for experienced and novice subjects across listening environments and measurement times. Although the magnitude of objective benefit was small, the mean result of 8.8 rau for experienced hearing aid wearers was essentially consistent with the mean of 10.3 rau reported by Cox and Alexander (1991a) for similar subjects and measurement procedures.

Because the experienced subjects had somewhat more hearing loss than the novice subjects (see Fig. 1), we postulated that the apparent effect of experience might actually reflect a difference in hearing loss. To explore this possibility, a second analysis was run, using speech reception threshold as a covariate. In this second analysis, the effect of experience was not significant, suggesting that the difference in objective benefit between experienced and novice subjects was related to the difference in hearing loss. Because the effects of experience did not interact with other variables, data from experienced and novice subjects were combined for further analysis of the effects of measurement time.

Figure 2 depicts the mean initial and long-term ben-

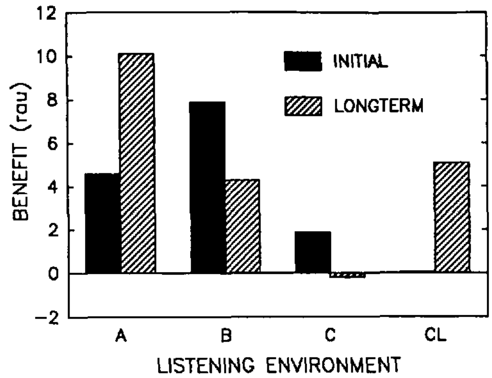

Figure 2. Mean initial and long-term objective benefit for each listening environment.

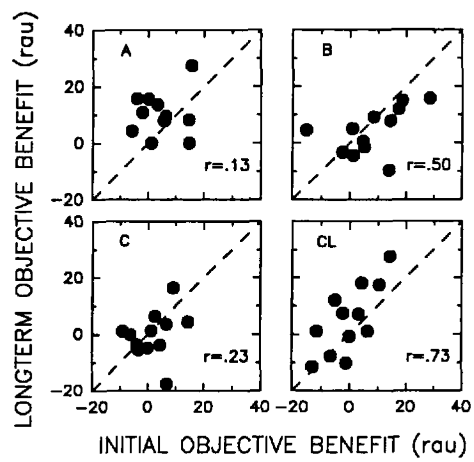

Figure 3. Relationship between initial and long-term objective benefit for individual subjects in each test environment. Linear correlation coefficients are given for each panel.

efit for each listening environment across all subjects. Examination of this figure quickly reveals that the pattern of mean benefit across listening conditions was considerably different for the initial and long-term measurements. In the initial measurements, average benefit was greatest for environment B, less for environment A, and negligible for environments C and CL. After 10 weeks, however, mean benefit was substantially greater in environments A and CL, but less in environments B and C. Two-way repeated measures ANOVA (listening environment × measurement time) produced a significant interaction between the variables [F3,33) = 3.28, $p < 0.05$). Tests for simple main effects indicated that the increase in mean benefit seen in environment A was statistically significant ($p < 0.05$), and in environment CL, the increase approached statistical significance ($p < 0.07$). However, the apparent decreases in benefit in environments B and C were not statistically significant.

A major focus of interest in this study was the relationship between initial measurements of objective benefit and corresponding long-term measurements. One way to evaluate that is illustrated in Figure 3. This figure shows the relationship between initial and long-term benefit in each of the test environments. Each symbol depicts the pair of scores for one subject. If benefit for an environment generally improved over time, most of the symbols would be above the diagonal. If subjects tended to maintain their rank order over time, that is, if those who obtained relatively high (or low) benefit at initial measurement continued to perform at these relative levels on the subsequent measurement, the symbols would form an irregular line that is generally parallel to the diagonal. In Figure 3, most of data for environments B and C are scattered close to the diagonal, indicating that for most subjects, benefit did not change very much and subjects did tend to retain their rank order over time (although there are some notable exceptions). In environment CL, the data for most subjects are above the diagonal, indicative of increased benefit over time. Also, the slope of the diagonal is generally maintained, indicating that subjects also tended to retain their rank order in this environment. In environment A, most of the symbols are again above the diagonal, showing improved benefit over time, but the data do not follow a diagonally sloped line. Inspection indicates that some subjects who tended to achieve relatively little benefit on the initial measurement were among those with the greatest benefit on the long-term measurement, thus disrupting the rank ordering in this environment.

Statistical evaluation of these data suggested that the relationship between initial and long-term benefit was limited. Correlation coefficients were small in environments A, B, and C (0.13–0.50) and moderate in environment CL (0.73). This outcome was not surprising given the relatively small between-subject variability in objective benefit, combined with the modest reliability of speech understanding tests. Under these circumstances, it is probably more informative to evaluate the relationship by inspection of the individual data as in Figure 3.

Subjectively Measured Benefit

Ten subjects completed subjective measurements of hearing aid benefit using the PHAB 2 weeks (initial benefit) and 10 weeks (long-term benefit) after the hearing aid fitting. Three subjects were previous hearing aid wearers and seven were new wearers. Two subjects who provided objective benefit data were absent from this group because they did not satisfactorily complete both PHAB inventories. As noted earlier, the PHAB inventories were scored in terms of the five subscales dealing with speech understanding: FT, EC, RV, RC, and BN.

In the first analysis of these data, the group was divided into experienced and novice subjects to explore the effect of experience on subjective benefit data. A three-way split-plot ANOVA (experience × subscale × measurement time) revealed a significant effect of experience with the mean subjective benefit for experienced subjects (51.4%) greater than the mean subjective benefit for novice subjects (15.0%) [$F(1,8) = 23.7$, $p <$

0.05). However, none of the interactions with experience was significant, indicating that the pattern of subjective benefit data was the same for experienced and novice subjects across subscales and measurement times. These results parallel those reported earlier for the objective benefit data. Again, we postulated that the difference between experienced and novice subjects could be largely explained by the difference in their hearing losses. To explore this, a second analysis was run using speech reception threshold as a covariate. In this analysis, the effect of experience remained significant, indicating that the difference in subjective benefit between our experienced and novice subjects could not be attributed to the difference in their hearing losses. Because the effect of experience did not interact with the other variables, data for all subjects were combined for continued exploration of the effects of measurement time on benefit.

Figure 4 depicts the mean initial and long-term subjective benefit scores for the five subscales. Subscales FT and EC evaluate speech understanding in fairly quiet conditions and, thus, should correspond roughly to environment A in the objective test protocol. Subscale RV evaluates speech understanding in reverberant settings and should correspond generally to the objective measurements in environment B. Subscale BN is concerned with communication in the presence of relatively high ambient noise. It corresponds best with objective environment C. Subscale RC does not have a clear counterpart in the objective tests, but might correspond to environment CL because of the absence of visual cues in that objective test setting. Examination of Figure 4 shows that substantial benefit was reported in all subscales, with the greatest benefit reported in subscale BN and the least in subscale FT. Furthermore, the mean subjective benefit score increased between the initial and long-term measurement for every subscale.

A two-way repeated measures ANOVA (subscales × measurement × time) revealed a significant effect of measurement time with the mean initial benefit of 22.9%, significantly less than the mean long-term benefit of 28.9% [$F(1,9) = 4.77$, $p = 0.05$]. However, the interaction between subscales and measurement time was not significant, indicating that this pattern of increase over time was not statistically different across subscales.

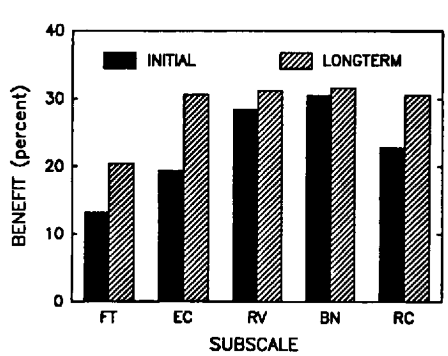

Figure 4. Mean initial and long-term subjective benefit for each of the PHAB speech communication subscales.

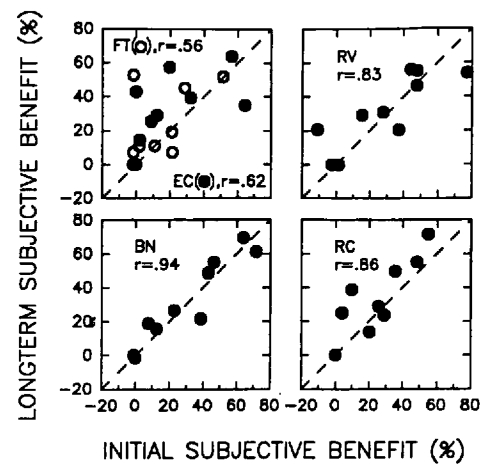

Figure 5. Relationship between initial and long-term subjective benefit for individual subjects in each PHAB subscale.

The subjective benefit data were also examined to determine the extent to which the initial PHAB scores were related to the long-term PHAB scores. Figure 5 shows the relationship between initial and long-term benefit scores for each subject. Each symbol represents the pair of scores for one subject. The two subscales corresponding to environment A (FT and EC) are shown in the same panel. Both produced a relatively wide scatter of data points, indicating that the benefit estimate obtained after 2 weeks of hearing aid use was not closely related to the corresponding benefit estimate made after 10 weeks. The lower correlation coefficients for these two scales (0.56 and 0.62, respectively) also attest to this outcome. The other three subscales, RV, BN, and RC (corresponding to environments B, C, and CL, respectively), all produced data more tightly clustered around a diagonal line, resulting in relatively high correlation coefficients of 0.83, 0.94, and 0.86, respectively. For these subscales, the benefit estimate obtained after 2 weeks of hearing aid use was a relatively good predictor of the estimate that would be obtained after 10 weeks; subjects who generated relatively high (or relatively low) initial scores also generated relatively high (or relatively low) long-term scores. In all four panels, most of the data points are above the diagonal, consistent with the statistical result indicating greater long-term benefit than initial benefit.

Relationship Between Objective and Subjective Benefit

Sixteen subjects provided long-term objective and subjective benefit data, including the five experienced hearing aid wearers who were not fitted with new hearing aids (due to a technical problem, data for one subject in environment CL could not be used). These data were examined to determine whether there was a relationship between objectively measured benefit in environments A, B, C, and CL and subjective benefit measured for the PHAB subscales that were hypothesized to correspond to these types of listening settings. Accordingly, five linear correlation coefficients were computed using data from the following pairs: environment A and subscale FT, environment A and subscale EC, environment B and subscale RV, environment C and subscale BN, and environment CL and subscale RC. Means and SD of the benefit data are shown in Figure 6. The correlation coefficients are shown in Table 1.

The correlations for environment A versus FT and environment B versus RV were statistically significant. These results suggest that subjects who score relatively highly on an objective benefit test using normal conversational speech level and relatively low noise will tend to be the ones who award themselves relatively high subjective benefit on items that address face to face communication in a living room type of setting. Similarly, persons who score relatively well on an objective benefit test featuring a somewhat raised speech level and moderate reverberation will also tend to score highly on subjective benefit items that concern listening to speech in a classroom lecture or religious service type of setting.

There were no significant correlations between objective benefit in environments C and CL and subjective benefit in the corresponding subscales. In other words, objective benefit scores obtained under conditions of somewhat raised voice and relatively poor SBR were not predictive of subject's evaluation of their own performance in everyday situations, where speech understanding is limited by high background noise or reduced speech cues.

One factor that would be expected to impact the relationship between objective and subjective benefit scores is the similarity of the objective test environments to those experienced by the subjects in daily life. To assess this, subjects were asked to comment on the similarity of the test environments to their own daily life experiences in settings that the environments were intended to simulate. In addition, they provided a similarity rating on a scale from 1 (low similarity) to 10 (high similarity). The median rating for all environments was in the 8 to 9 range, suggesting that the subjects generally thought the tested listening environments to be rather similar to real life. However, the comments revealed that although environment A was judged quite similar to daily life, environment B was, in the main, considered to be harder than most corresponding daily life settings and environment C was evaluated as generally easier.

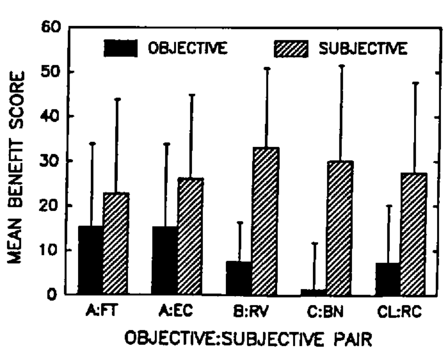

Figure 6. Mean long-term benefit for five pairs of objective/subjective test conditions. Error bars give 1 SD.

Table 1. Correlation coefficients between benefit scores obtained in simulated listening environments and benefit scores obtained for corresponding subscales of the Profile of Hearing Aid Benefit.

Objective Test Environment	PHAB Subscale				
	FT	EC	RV	BN	RC
A	0.61*	0.20			
B			0.51*		
C				0.35	
CL					0.13

* *p < 0.025 (one-tailed).*

Selected Gain Levels

It was postulated that the gain chosen for a newly fitted hearing aid might be different from that chosen for the same hearing aid after 10 weeks of use, and that the gain settings might affect benefit scores. To monitor gain settings, the gain level selected for each objective test environment was recorded in terms of the 2-cc coupler gain at 2000 Hz. A three-way split-plot ANOVA of these gain data (experience × test environment × measurement time) revealed that there were no significant main effects except for that of test environment [$F(3,30) = 7.44, p < 0.05$], and there were no significant interactions. These results indicate that when the volume control was set using a bracketing procedure while listening to the target speech, as in this study, there were no systematic differences in preferred gain at 2000 Hz for experienced and novice subjects or between initial and long-term measurements. The choice of different gain settings for different listening environments was expected. We have reported similar data elsewhere (Cox & Alexander, 1991b).

DISCUSSION

In this investigation, we sought to determine whether hearing aid benefit improves significantly over the first 10 weeks of hearing aid use and whether the changes in benefit (if any) were affected by the type of benefit measurement (i.e., objective or subjective). In addition, we assessed the relationship between subjective and objective benefit data. Finally, we hoped to determine whether time-related changes in benefit would be similar for novice and experienced hearing aid users. Unfortunately, few experienced amplification users who had been fitted with new hearing aids completed the long-term benefit measurements. Thus, the data must be considered tentative and interpreted with caution as it relates to the issue of hearing aid experience.

The objective measures of hearing aid benefit produced data indicating that hearing aid benefit does improve during the first 10 weeks of use, at least in some types of listening environments. Moreover, both novice and experienced hearing aid users gave evidence of similarly improved performance over time after the fitting of a new amplification system. This outcome supports the hypothesis that adjustment to a new hearing aid includes optimization of speech understanding, as proposed by Barfod (1979). Furthermore, because visual cues were provided in environments A, B, and C, increased benefit in these environments would imply improved use of auditory cues that are not redundant with visual cues.

The clearest improvements were seen in the living room type of environment (environment A). After adjustment to the hearing aid, this was the environment which registered the largest benefit. In listening environments B and C, representing reverberant and noisy everyday settings, respectively, no significant improvements were seen in objectively measured benefit after the adjustment period. Both of these environments registered less long-term benefit than environment A. It was interesting to note the rather large decrease in mean benefit over time in environment B. Although this change was not statistically significant in the present study, further investigation with a larger sample is warranted to explore possible influences of simulated reverberation on initial benefit data.

Because of the relatively large initial benefit in environment B, the pattern of mean initial benefit across listening environments did not match the pattern seen in our previous work measuring objective benefit in real everyday environments (Cox & Alexander, 1991a). However, the long-term finding of maximum benefit in environment A, less benefit in environment B, and negligible benefit in environment C was consistent with our previous work as well as with several other studies that reported subjectively assessed benefit in different everyday situations (e.g., Cox et al, 1991; May, Upfold, & Battaglia, 1990; Scherr et al. 1983).

The data for environment CL, suggesting that benefit improved over time in this type of setting, provided an unexpected finding. Although this effect did not quite reach the 5% level of significance in the present small sample study, its implications are important enough to demand further exploration. The only difference between environments C and CL was the presence or absence of visual cues. Because Cox & Alexander (1991a) reported that visual cues did not affect hearing aid benefit (the same benefit was measured with visual cues present and absent), we expected to observe similar results in environments C and CL. Instead, there seemed to be improved benefit over time in the noisy environment without visual cues (environment CL), but not in the noisy environment with visual cues (environment C). At first glance, this seems inconsistent with the findings of the previous study. However, the two studies can be reconciled if we note that the benefit data reported by Cox and Alexander (1991a) corresponded to the initial measurements in the present study. The difference between initial and long-term results could be explained if the hearing aid users learned to make more effective use of newly provided auditory speech cues that are redundant with visual cues. For example, auditory cues for place of articulation, which reside mostly in higher frequencies (Miller & Nicely, 1955), would be enhanced in most hearing aid fittings due to high-frequency emphasis. However, speech reading provides substantial place of articulation cues (Walden, Prosek, Montgomery, Scherr, & Jones, 1977). Thus, an improved use of audible place cues might not be observed in a condition where visual cues were provided. However, when visual cues were absent, an improved use of place cues provided by the hearing aid would result in greater benefit in the long-term test condition than in the initial test condition. Future work should address this hypothesis with a larger group of subjects.

The measures of subjective benefit at 2 weeks and 10 weeks postfitting revealed that self-assessed benefit also improved considerably over the adjustment period for both experienced and novice hearing aid wearers. Furthermore, subjective benefit improved in all of the assessed daily life situations, including reverberant and noisy situations (subscales RV and BN). This outcome is not consistent with the objective data because the latter indicated that benefit did not improve over time in reverberant and noisy situations (environments B and C). However, it is interesting to note that the largest increases in mean subjective benefit over time were seen for subscales FT, EC, and RC. These subscales correspond best to objective measurement environments A and CL, which also registered the greatest mean benefit improvements over time (see Fig. 2).

The pattern of mean subjective benefit across subscales (Fig. 4) was not consistent with the mean objective benefit data (Fig. 2). Based on the objective data, we would have expected subjects to award themselves more benefit in the subscales corresponding to environment A (subscales FT and EC) than in subscales BN and RV. Instead, self-assessed benefit was greatest in subscales RV and BN and least in subscales FT and EC. In searching for an explanation for this outcome, we hypothesized that the pattern of benefit across subscales might arise as a consequence of the unequal intervals defined in the seven-point response continuum for the PHAB (see earlier description). To explore this possibility, the PHAB results were rescored using equal intervals between descriptors in place of the customary percentages. This operation did not change the outcome. Thus, we could not conclude that the pattern of benefit across PHAB subscales was an artifact of the response choices provided to subjects.

As noted above, a number of previous studies of self-assessed benefit, including our own (Cox et al, 1991), reported a pattern across listening environments that was consistent with the objective benefit data. The different pattern found in the present study may have been partially due to the relatively mild hearing impairments of these subjects. Recall that to complete the PHAB, subjects assess the proportion of daily life situations in which they experience communication problems both with and without their hearing aids. Benefit is then quantified as the difference between aided and unaided responses. Examination of the aided and unaided data revealed that this group of mild to moderately impaired subjects judged themselves to have problems a relatively small proportion of the time, even without their hearing aids, on the items comprising the FT subscale. As a result, the benefit possible from a hearing aid was limited on this subscale.

There were interesting parallels between objective and subjective data with respect to the relationship between initial and long-term benefit. Comparisons of Figures 3 and 5 reveals considerable overall similarity between them. With both measurement approaches, data corresponding to environments A and CL indicated more improvement over time than those depicting environments B and C. Also, both sets of data suggested that initial measurements of benefit for environment A situations were relatively poor predictors of long-term benefit in that environment, whereas initial measurements in the other three were more closely related to corresponding long-term data. On the other hand, correlations between initial and long-term benefit were substantially higher for subjective than for objective measurements in all environments. This outcome was partially due to the greater between-subject differences observed when benefit was self-assessed (Fig. 5) rather than objectively measured (Fig. 3).

In evaluating these results obtained with objective and subjective measurement approaches, it should be kept in mind that the initial subjective measurement was obtained after subjects had used the hearing aid for 2 weeks, whereas the initial objective measurement was obtained before subjects had accumulated any significant experience with the instrument. Given this procedural difference, it is perhaps surprising that the relationship between initial and long-term benefit was so similar across the two sets of data.

Despite their overall similarity, Figures 3 and 5 also illustrate a major difference between the objective and subjective benefit data: the size of subjective benefit was often much greater than that of objective benefit. As Figure 5 shows, subjective benefit sometimes approached 80%, whereas, as seen in Figure 3, objective benefit seldom exceeded 20 rau (similar to 20%). This difference is seen even more plainly in Figure 6, which depicts mean benefit in each of the environment/subscale pairs that are assumed to be comparable. In the data for environments B and C, objective benefit was very small and yet the subjective responses for subscales RV and BN were indicative of substantial self-assessed benefit. We have not previously obtained both types of data from the same subjects; however, these results are consistent with previous separate studies of objective (Cox & Alexander, 1991a) and subjective (Cox et al, 1991) benefit using these measurement procedures.

Although both sets of data quantify changes in speech intelligibility due to the hearing aid, it is not necessarily surprising that they have different dimensions. The objective data reflect change in the proportion of words understood and thus directly indicate the magnitude of benefit. The subjective data, on the other hand, reflect proportion of daily life situations in which intelligibility is improved, but do not indicate the amount of improvement. Consider, for example, the mean subjective benefit of 31% for subscale BN (Fig. 6). This should be interpreted as indicating that amplification improves communication in noisy situations about one-third of the time. However, these data do not indicate the amount of improvement realized in these situations.

Regardless of the different rationales underlying the objective and subjective measurement approaches, it is desirable for the two types of procedures to produce related data, and it seems reasonable to postulate that they would do so. That is, individuals who achieve relatively large objective benefit in a particular type of listening environment should also report a relatively high frequency of improved communication in the same type of listening environment in daily life. If a relationship can be established between objective and subjective benefit data, this would be an important step toward establishing valid predictions of long-term, real world benefit at an early stage in the hearing aid fitting process.

In the present investigation, the relationship between subjective and objective long-term benefit was assessed using correlation coefficients. The results (Table 1) indicated that a statistically significant relationship between objective and subjective benefit was observed between environment A and subscale FT, and between environment B and subscale RV. The three other postulated environment/subscale pairs did not produce significant relationships. Although the A-FT and B-RV correlations were statistically significant, they were not very large (0.61 and 0.51, respectively). As a result, predictions of subjective benefit from objective benefit data would not be very precise, even for these two environments. It should be realized that these modest correlation coefficients occur, in part, because of the measurement errors associated with the subjective and objective measurement procedures. It is possible to use the test-retest correlations associated with each procedure to "correct" a correlation between procedures and thus derive an estimate of the underlying relationship between the two variables, that is, the correlation that would be observed if there were no measurement error (Carmines & Zeller, 1979).

To estimate the underlying relationship between objective and subjective benefit data for the A-FT and B-RV pairs, their correlations were corrected using test-retest correlations derived from other studies with hearing-impaired subjects. The assumed test-retest correlations were 0.86 for objective environments A and B

(R.M. Cox, L.L. Hurdle, & T.R. Pullin, unpublished data) and 0.55 and 0.63 for subscales FT and RV, respectively (Cox & Rivera, in press). The corrected correlations were 0.89 for the A-FT pair and 0.69 for the B-RV pair. These correlation coefficients indicate a strong to moderate relationship between objective benefit in environments A and B and subjective benefit on PHAB subscales FT and RV, respectively. Evidently, the sound room simulations of environments A and B produced listening conditions with considerable relevance to daily life experiences for hearing aid wearers.

It was disappointing to note the lack of a significant relationship between objective benefit measured in environment C and subjective benefit measured using subscale BN. This suggests that the listening condition for objective benefit measurements failed to accurately simulate the listening conditions addressed by subscale BN. This subscale is intended to tap the problems experienced by hearing aid wearers in attempting face to face communication in noisy everyday environments. It encompasses a variety of types of background noises, including crowds, groups, traffic noise, and busy stores and restaurants (see Cox & Gilmore, 1990, for an item listing). Clearly, a single listening environment cannot realistically reproduce all of these settings. However, because the internal consistency of subscale BN is fairly high [coefficient α determined to be 0.87 by Cox et al (1991) and 0.83 by Cox and Rivera (in press)], it seems reasonable to postulate that a single listening condition could adequately represent all of these settings. Objective environment C was designed to simulate the well-known "cocktail party" setting, a setting that is addressed in one of the items in subscale BN. However, subjects generally evaluated listening in environment C as easier than in daily life. When asked to comment on the similarity of the environment C listening environment to listening "at a party," several subjects noted that the multitalker babble used as a competing signal was not as intrusive as ambient noise encountered at social occasions in daily life. The lack of relationship between our objective benefit measurements and the subjective benefit registered in subscale BN may have been due to this insufficiently accurate simulation of the cocktail party setting. Future investigations will address this issue.

As noted above, the number of experienced hearing aid wearers who completed both initial and long-term benefit measurements was small. Nevertheless, the results suggested interesting differences between experienced and novice hearing aid users. In both objective and subjective benefit measurements, experienced hearing aid wearers obtained more benefit than first-time wearers. For the objective measurements, this outcome could be attributed to the greater hearing loss among the experienced subjects. However, differences in hearing loss between experienced and novice subjects were not sufficient to account for the very large differences between them in subjective benefit. This result was probably due to self-selection of the experienced subjects. Only those who believe that they are receiving significant benefit from their hearing aids are likely to continue using them long enough to become experienced instrument wearers. In contrast, the novice group of subjects presumably contained some individuals who were destined to become experienced wearers and some who will ultimately reject hearing aid use because of low perceived benefit. In fact, two of the eight novice subjects expressed clearly negative opinions about the help provided by their instruments at the conclusion of the study.

Despite the differences in magnitude of benefit between experienced and novice subjects, both groups evidenced similar changes in benefit over the 10 week adjustment period. Overall, these results suggest that amount of hearing loss is more important than previous hearing aid experience in determining the outcome of objective benefit measurements. However, when evaluating subjective benefit data, it should be kept in mind that the magnitude of benefit produced by experienced hearing aid wearers will probably overestimate the subjective benefit to be obtained from the corresponding group of all potential instrument wearers.

Final Comments

The results of this study have implications for both clinical and research applications. In both realms, potential amplification systems are often evaluated and/or compared using data analogous to the initial benefit data in this investigation. Our results suggest that this practice should be seriously questioned. The data indicate that initial benefit is a reasonably good estimate of long-term benefit in certain types of listening situations, namely, noisy and reverberant situations in which visual cues are fully available. Thus, for these types of settings, it might be defensible to assume that initial benefit data provide a valid estimate of results that would be obtained in the same listening conditions after adjustment to the hearing aid. However, the results also suggest that in listening situations typified by (1) face to face communication in low background noise, and (2) communication in a noisy setting without visual cues, experience with the hearing aid is likely to result in improved benefit, presumably because hearing aid wearers learn to optimize their use of new auditory cues that become salient in these types of situations. As a result, the initial benefit measurement will probably underestimate long-term results. These observations were generally true for both the objective and subjective benefit measurement approaches used in this study.

The correspondence between objective and subjective benefit data is another matter of considerable practical significance. Clinicians and researchers need to know whether objective benefit determined in a clinic or laboratory can yield an accurate prediction of the hearing aid wearer's own opinion about the help provided by the instrument in daily life. The results of this investigation were rather encouraging on this score because a reasonable correspondence was found between objective and subjective data in two important types of listening environments. However, in another setting that presents major problems for the hearing impaired (face to face communication with high background noise), correspondence was not seen between objective and subjective benefit data. Although these results suggest that it is possible to design sound room-based objective measurements that will be predictive of subjective data, further work is necessary to refine these procedures.

Finally, we must recognize the limitations imposed by small sample sizes in the present study. The results indicating significant maturation of hearing aid benefit in certain types of listening situations are highly intriguing and have substantial consequences for future hearing aid research and practice. However, a full delineation of these effects will require additional investigations encompassing larger subject groups. Similarly, the results describing relationships between objective and subjective benefit must be considered indicative until more data are accumulated. Given the potential ramifications of these matters, there is a clear need for continued exploration of the variables that determine hearing aid benefit.

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APPENDIX A Subject Schedule

Table A1. Schedule describing the distribution of subjects across the three phases of investigation: (1) comparison of initial and long-term objective data; (2) comparison of initial and long-term subjective data; and (3) comparison of long-term objective and subjective data.

Subject No.	New User	New Hearing Aid	Initial vs. Long-Term Objective	Initial vs. Long-Term Subjective	Subjective vs. Objective
1	Y	Y	Y	Y	Y
2	Y	Y	Y	Y	Y
3	Y	Y	Y	N	Y
4	Y	Y	Y	Y	Y
5	Y	Y	Y	Y	Y
6	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y
9	N	Y	Y	Y	Y
10	N	Y	Y	Y	Y
11	N	Y	Y	N	N
12	N	Y	Y	Y	Y
13	N	N	N	N	Y
14	N	N	N	N	Y
15	N	N	N	N	Y
16	N	N	N	N	Y
17	N	N	N	N	Y