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Impact of advanced hearing aid technology on speech understanding for older listeners with mild-to-moderate, adult-onset, sensorineural hearing loss

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Introduction

Hearing loss is among the most common chronic health conditions of older people [1]. In the USA, 27% of persons in their sixties, 55% of those in their seventies, and 79% of those in their eighties have bilateral hearing loss that is sufficient to impair communication in daily life [2]. Prevalence of hearing loss in Europe also is high [3]. Numerous studies have shown that hearing loss negatively affects quality of life in older adults [4]. When hearing loss cannot be medically alleviated, the customary treatment is amplification using hearing aids. When hearing aids are used, they have been shown to improve quality of life in older adults [5]. Despite these facts, less than 25% of older persons in the USA with acknowledged and/or verified hearing loss wear hearing aids [6]. In other countries that have been studied, reported adoption of hearing aids as a solution to existing hearing problems ranged from 14% in Japan to 43% in Norway [7].

Why do people with hearing problems not accept and wear hearing aids that could help to address those problems? Although numerous contributing variables have been identified, one theme that consistently is observed is the belief that hearing aids do not provide sufficient value to justify their expense [6]. It has been shown that patients perform a cost-benefit analysis to determine the value of hearing aids [8,9]. Devices that provide more benefit for a given cost, or the same benefit for less cost are considered to provide greater value. This suggests that hearing aids are more likely to be accepted if they provide greater benefit per unit of cost to the patient. These and other similar data support the proposition that although cost is not the only variable involved in hearing aid adoption, perceived benefit per unit cost has a central role in patient decisions.

Another factor that figures importantly in hearing aid adoption decisions by older adults is the hearing health care and advice they receive from their medical practitioners. In routine consultations health professionals have opportunities to refer patients for management of adult-onset hearing impairment and to share information about available hearing loss treatment options. Recommendations from general practitioners and other health professionals has been identified as predictive of actions that individuals with hearing

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impairment will take towards hearing rehabilitation [10]. The goal of this paper is to provide data-based information about the relative benefit of different levels of current hearing aid technologies with regard to speech understanding. It is hoped that this information will facilitate optimal management of hearing impairment for older adults with uncomplicated, mild to moderate, adult-onset, sensorineural hearing loss.

The issue of everyday life benefit per unit cost has received limited research attention for hearing aids. Hearing aid cost typically is determined by factors external to evidence-based benefit. Each hearing aid manufacturer commonly offers hearing aid “families” including 3–4 models that function at successively more sophisticated technology levels. As technology level rises, the hearing aid increases in cost. In 2013, modern hearing aids provide digital signal processing intended to improve outcomes in a variety of listening environments. The most common features are: multichannel compression which allows for independent adjustment of amplification in several frequency bands; directional microphones which can improve signal-to-noise ratio by amplifying sound from the front more than sound from other directions; and noise reduction algorithms which act to suppress unwanted noises. Hearing aids at the basic (lower) level of technology typically include a version of each of these features. However, premium (higher) level hearing aids include more complex, automatic and adaptive versions of the basic features, as well as some features that do not occur at all in the basic paradigm. Further information about these and other features is given below. It might seem obvious that the more advanced features a hearing aid has the more benefit the wearer will receive in daily life. If this is true, the benefit per unit cost will remain approximately constant, or even increase, when premium-feature hearing aids are purchased. However, increased real life benefit from premium features has not been established by independent research. Currently, practitioners rely mostly on unverified manufacturer claims about feature benefits when they decide which hearing aid(s) to recommend to patients. In this article, we report research designed to demonstrate the relative effectiveness of premium features compared with basic features in contemporary hearing aids. Two research questions were addressed:

1. Do premium-feature hearing aids yield better speech understanding than basic-feature hearing aids for persons with uncomplicated, adult-onset, mild to moderate, sensorineural hearing loss?
2. Does the answer to question (1) differ across exemplars of basic-feature and premium-feature devices from two different hearing aid manufacturers?

Methods

Study procedures were reviewed and approved by the University of Memphis Institutional Review Board. Each subject gave written informed consent at the outset. Participants were compensated for their time. The work was performed at the University of Memphis Hearing Aid Research Laboratory.

Participants

Participants were recruited from a database of willing research participants maintained by our laboratory and through word-of-mouth referral. Of 14 older adults contacted by mail and telephone, 11 volunteered to participate. Fifteen other participants who independently contacted our laboratory and met the inclusion criteria participated. One participant withdrew because of illness, 25 completed the research. To be accepted for the study, a participant needed to identify, in an initial interview, at least one specific situation in which he/she desired hearing help. Other inclusion criteria were: bilateral, adult-onset, mild to moderate, non-fluctuating, sensorineural hearing loss; absence of observed middle- or outer-ear pathologies; absence of reported retrocochlear pathology; absence of any other observed or reported hearing problems needing medical attention; good or excellent self-rated physical and mental health; native English speaker; and observed adequate corrected vision and literacy to complete informed consent, questionnaires, and the test of speech understanding. Participants were 17 men and 8 women, aged 61 to 81 years (mean = 70.4). Eleven were employed full-time, four worked part-time, the rest were retired.

Both new and experienced hearing aid users were eligible for the study. This allowed us to sample typical individuals across the range of mild to moderate hearing loss. Most older adults with mild hearing loss do not currently wear hearing aids (although many are interested in whether amplification would help them); and many with moderate hearing loss do wear hearing aids. The presence/absence of pre-study experience with hearing aids was not expected to be a confounding variable because the lengthy field trial undertaken with each research hearing aid made all subjects experienced users by the time outcomes were measured. Thirteen participants had worn hearing aids before. Figure 1 depicts the mean audiograms of new and experienced users. Thresholds for left and right ears were averaged for each subject. Mean mono-syllabic word recognition scores in quiet were 82.6% (SD=12.9%).

Hearing Aids

Four pairs of commercially available hearing aids were evaluated. They exemplified basic-level and premium-level technology from each of two major manufacturers, released in 2011 and still on the market at this writing. They were mini behind-the-ear thin-tube devices similar to the most popular style currently marketed. Each pair was linked with wireless communication. Basic and premium devices from the same manufacturer were identical in appearance, but there were substantial differences in advertised features and functions. Table 1 summarizes the advertised differences across basic and premium features for the hearing aids used in this research. The hearing aids were fitted with three user-selectable programs. Subjects were trained on the purpose and function of the programs. Remote controls were provided to change programs and volume. The programs were as follows:

- Program 1 (the default listening program) was labeled the Everyday program and it was configured with all features implemented as recommended by the manufacturer to optimize that hearing aid for that individual’s hearing loss. The Everyday program automatically adjusted the hearing aids’ features in different environments. It is theoretically expected that these automatic adjustments will be more advantageous for the listener when premium-level features are used compared to basic-level features.

- Program 2 was labeled the Look-&-Listen program. This program was configured like program 1 with the exception that it engaged the strongest non-adaptive front-facing microphone directionality. The technology for microphone directionality uses binaural data streaming in premium-feature devices, so they are expected to provide better rejection of background noises when speech is produced in front of the wearer in a setting such as a cocktail party.
- Program 3 was labeled the Speech-Finder program and it was configured l ike program 1 with the exception that it included the most effective technology in each hearing aid for detecting speech that is produced from the sides and behind. The technology to accomplish this uses binaural data streaming in premium-feature devices, so they are expected to provide better ability to detect a talker in situations where speech might come from different directions, such as driving a car with passengers.

Procedure

Participants were told that the research was about "how people benefit from different types of modern hearing aids". They were otherwise blinded about the study. Participants used each pair of hearing aids for one month in their daily lives. Counterbalancing controlled the order in which the two manufacturers were presented and the order of using basic and premium technology. When the basic and premium hearing aids from the first manufacturer had been evaluated, there was a one-month washout period before hearing aids from the second manufacturer were used. There is no information about whether a washout period is essential for this type of research. During the wash-out period, previous users were allowed to wear their personal hearing aids.

Each binaural hearing aid fitting was accomplished using a comprehensive best-practice five-step approach. First, hearing aids were programmed using the manufacturer's proprietary algorithm. Second, real-ear performance was matched to the National Acoustics Laboratory Non-Linear prescription goals [11]. Third, the fitting was fine-tuned using rule-based subjective assessments of bilateral loudness balance, loudness of average speech, loudness comfort, and quality of own voice. Fourth, follow up telephone interviews and further fine-tuning were completed as needed within the first week of use. Finally, remote controls and hearing aid learning capabilities (for premium devices[1]) were available throughout the month of wearing time to further optimize hearing aid performance in daily life. Table 2 summarizes the extent to which the amplification achieved in the final fitting of each hearing aid differed from the NAL-NL2 prescription. Comparison of data for each premium/basic pair shows that the mean differences varied by only 1–2 dB.

When planning the research, it was decided that an effect size of about .50 (a medium effect using the convention for Cohen's *d* [12]) would be the minimum interesting difference between premium-level and basic-level outcomes. An effect of this size would mean that about 20% of individuals wearing premium-level hearing aids would perform at levels

[1]Learning capabilities allowed premium hearing aids to make volume adjustments automatically rather than manually. This is a convenience feature. It would not be expected to systematically affect speech understanding in this research design.

above the distribution for individuals wearing basic-level hearing aids. Another way to envision the practical consequences of a medium effect is to note that it would create a probability of about .64 that an individual would yield a superior outcome with premium-level hearing aids than with basic-level hearing aids (keep in mind that with a zero effect, this probability would be .5) [13]. Power computation used the software G*Power version 3.1.7, configured for: ANOVA: repeated measures, within factors; alpha=.05; and 4 measurements [14]. The research had >80% power to detect a medium effect favoring premium feature technology level.

Outcomes

Although hearing loss gives rise to many problems that impact quality of life, the most frequently reported difficulty, and the one that generally is noticed before others, is loss of ability to understand speech in an environment with background noise such as a restaurant [15]. Improved understanding of speech in noisy settings is the hearing aid feature that is most desired by hearing aid users [16,17]. Consequently, the outcomes reported here are centered on improvements in speech understanding and increase in quality of life.

The strategy for outcome measurement was designed using three types of measures. The first type was laboratory testing. These data have the advantage of rigorous stimulus control; however, the accuracy of simulation of daily life listening condition is unknown for each individual. The second type was standardized questionnaires. These outcome data have the advantage of accurately addressing real life situations for each individual, however, it is not known whether the addressed listening conditions were highly relevant to the individual, or other highly relevant conditions were not addressed. The third type was participant diaries. These outcome data have the advantage that they focus on the most salient listening experiences for each individual, however, data analysis is cumbersome and interpretation is challenging. By integrating outcomes from the three types of measures, we were able to obtain a comprehensive representation of the answers to the research questions stated above.

Laboratory Speech Understanding—Speech understanding was quantified using an American dialect version of the Four Alternative Auditory Feature test (AFAAF) [18,19]. Each score was based on the accuracy of closed-set identification of test words presented in the sentence: “Can you hear __ clearly?” A typical test utterance is: “Can you hear COLD clearly?” and the four alternatives displayed for the participant on a computer screen are: HOLD, OLD, COLD, and GOLD. Because it calls for consonant recognition with minimal linguistic context, the AFAAF test was expected to be sensitive to any audibility or clarity improvements that might have resulted from use of premium hearing aid features rather than basic features.

Speech understanding was evaluated in three listening environments which covered most of the range of levels and signal-to-noise ratios typically experienced in everyday life. As ambient noise increases, a talker will try to maintain intelligibility by increasing his/her speech level. The conditions we tested simulated everyday speech levels with soft, average, and loud background noise. During the test, the three listening environments were randomly interleaved. An 80-item list was tested in each simulated environment.

Testing was conducted in a sound-treated room with speech delivered from a loudspeaker one meter from the seated subject at 0° azimuth. Loudspeakers placed at 135°, 180°, and 225° delivered masker noises. Hearing aids were set to the Everyday program with the volume adjusted as used in daily life. A steady-state noise with a talker-matched spectrum was high-pass and low-pass filtered with a cutoff of 1500 Hz to create the masking noises. The testing arrangement was designed to be reasonably realistic while also providing an opportunity for the basic-level and premium-level features to optimize the signal at the subject's ears according to their different capabilities.

Standardized Questionnaires—At the end of each 1-month trial, participants completed four questionnaires. Three were selected to yield data for real-world speech understanding and the fourth was a measure of quality of life changes.

1. The Abbreviated Profile of Hearing Aid Benefit (APHAB) measures hearing problems in everyday situations [20]. Scoring yielded Global speech communication scores for both aided and unaided listening.
2. The Speech, Spatial and Qualities of Hearing Scale (SSQ) assesses hearing difficulty in challenging and dynamic listening circumstances [21]. The version SSQ-B was used to measure the benefit of hearing aids [22]. Scoring yielded an overall score for speech understanding benefit (or deficit) from using amplification.
3. The Device-Oriented Subjective Outcome (DOSO) Scale asks the listener to specify how well the hearing aids perform in different situations [23]. One subscale yielded a score for speech understanding.
4. Participants rated change in overall quality of life related to hearing when listening with the trial hearing aids. They used a 15-point response scale [24].

Participant Diaries—Participants received a blank diary for each of the four one-month trials. They used the diaries to describe in their own words one communication situation that went well, and one that went poorly, each day for five days at the end of the trial. By this method, they recounted experiences with the hearing aids that were most memorable to them each day. These data were analyzed using qualitative content analysis [25].

Results

Analysis of Laboratory and Questionnaire Outcomes

General Linear Model (GLM) repeated measures analysis of variance (ANOVA) with planned independent contrasts was used to analyze these data. Compared to the more typical omnibus F-test followed by post-hoc comparisons, this analysis approach has been shown to provide increased statistical power without inflating the experiment-wise error rate [26,27].

The planned contrasts were driven by a priori hypotheses that:

1. Outcomes would be better when listeners wore hearing aids than when listeners did not wear hearing aids (a necessary precursor to research questions 1 and 2).

2. Outcomes would be better for premium-feature hearing aids compared to basic-feature hearing aids for both manufacturers combined (research question 1).

3. Outcomes would be better for premium-feature hearing aids compared to basic-feature hearing aids for each manufacturer separately (research question 2).

For all tests, values of $p \leq .05$ are reported as significant and values of $p > .05$ but $\leq .1$ are considered worthy of mention.

Laboratory Speech Understanding

Figure 2 depicts mean speech understanding in noise in each tested condition. It is seen that unaided listening (black bars) consistently produced lower scores than each aided listening condition. The differences among the four aided conditions appear relatively small. Separate statistical analyses including the planned contrasts described above were carried out for each listening environment (soft, average, and loud), with the following results:

Soft Listening Environment—There was a significant main effect of the five listening conditions (unaided and four aided) on speech understanding, $F(4, 96) = 3.83$, $p = .006$. Contrast 1 revealed that aided listening yielded significantly higher scores than unaided listening, $F(1, 24) = 9.65$, $p=.005$. Contrast 2 did not produce a significant result, ($p=.17$). Thus, aided listening using premium features did not produce better scores than aided listening using basic features, overall. When the difference in performance between premium and basic features was compared for each manufacturer, manufacturer A (contrast 3) produced a noteworthy result ($p=.08$) but manufacturer B (contrast 4) did not ($p=.5$). However, the data for manufacturer A suggested a trend for the basic-feature hearing aid to yield better scores than the premium-feature device, which is opposite to the hypothesized outcome.

Average Listening Environment—There was a significant main effect of the five listening conditions on speech understanding, $F(2.4,57.6)$[2] $= 8.04$, $p<.001$. Contrast 1 revealed that aided listening yielded significantly higher scores than unaided listening, $F(1, 24) = 13.43$, p=.001. None of the other planned contrasts (2, 3, or 4) yielded significant results, indicating that performance was not significantly different for premium and basic conditions.

Loud listening Environment—There was a significant main effect of the five listening conditions on speech understanding, $F(4,96) = 2.87$, $p=.027$. Contrast 1 revealed that aided listening yielded significantly higher scores than unaided listening, $F(1, 24) = 6.86$, $p=.015$. None of the other planned contrasts (2, 3, or 4) yielded significant results, indicating that performance was not significantly different for premium and basic conditions.

Computation of Effect Size—As noted earlier, a medium effect ($d = .50$) was considered the minimum noteworthy difference in outcome between premium-level and basic-level hearing aids. To determine the effect size for laboratory speech understanding,

[2]Degrees of freedom have been corrected using Greenhouse-Geisser estimates of sphericity.

the average score across the three listening environments was computed for basic-level conditions for each subject. The same computations were made for premium-level conditions. The computed effect of premium versus basic technology was $d = -.06$ with a 95% confidence interval from −.45 to .33. This result indicates that it is improbable that the population effect size is as large as .50.

Standardized Questionnaires

Speech Understanding Benefit—Because the APHAB questionnaire was answered for both unaided and aided listening, this questionnaire was used to explore the extent to which outcomes were better in daily life when listeners wore hearing aids than when they did not wear hearing aids (a priori hypothesis 1, above). Figure 3 depicts reported frequency of success in speech communication situations for each of the five tested conditions, as measured using the APHAB. The pattern of differences across unaided and aided listening is similar to that seen in each of the laboratory-simulated environments in Figure 2. Analyses revealed a significant main effect of the five listening conditions on speech understanding, $F(2.3, 55.3) = 34.05$, $p<.001$. Contrast 1 revealed that aided listening yielded significantly higher scores than unaided listening, $F(1, 24) = 57.14$, $p<.001$. None of the other planned contrasts (2, 3, or 4) yielded significant results, indicating that frequency of communication success in everyday life was not significantly different for premium and basic conditions.

Three questionnaires yielded measures of the benefit (or deficit) obtained in daily life from using amplification. To provide a single comprehensive benefit/deficit score for each hearing aid, data from each questionnaire were rescaled into a 0 to 10 scale format in which a higher score denoted more benefit. Then, the three re-scaled scores were averaged for each hearing aid for each subject. Figure 4 depicts the resulting composite benefit scores for each hearing aid. All the hearing aids produced very similar mean benefit scores of about 6 on a scale from 0 to 10. Analyses determined that there was not a significant main effect of the four aided listening conditions on speech understanding benefit (p=.6). None of the planned contrasts (2, 3, or 4) yielded significant results. Thus, reported real-world benefit for speech understanding was not significantly different across the four aided conditions or between basic-level and premium-level hearing aids.

Quality of Life Changes—At the end of the month-long trial with a given pair of hearing aids, each subject described the extent to which using those hearing aids had changed his/her quality of life related to hearing, compared to listening without hearing aids. Subjects responded on a 15-point scale extending from “A very great deal worse” through “No change” to “A very great deal better”. The 25 data points provided for each hearing aid condition are summarized in Figure 5. In this chart, the smallest bubbles indicate the response of a single subject. Bubble size increases in proportion to the number of subjects giving that score.

Ninety-six percent of the responses (all but four) indicated that the hearing aids made quality of life at least “a little better”. Mean ratings for each hearing aid condition were close to “A good deal better”. Many subjects judged the hearing aids to have produced changes that were characterized as “good”, “great” and “very great”. Three responses (marked with a star) suggest that the hearing aids had minimal impact on quality of life. Additionally, one subject rated one hearing aid condition with a score of −5 indicating that it caused quality of life to be "a good deal worse". These data were statistically analyzed using the parametric approach described above (GLM repeated measured ANOVA with planned contrasts). In addition, the non-parametric Freidman ANOVA by ranks was completed. There were no significant differences in quality of life changes between premium and basic conditions in any test.

Daily Diaries

Using the blank five-day diaries provided, each participant described successful and unsuccessful communication situations that occurred in daily life while they were wearing the hearing aids. There were 40 statements per participant, and 1000 total statements. Each of these statements served as a meaning unit for analysis. Three trained researchers used codes to describe the content of each statement. Dialogue among the three coders helped to validate the codes and to cross-check and revise them as necessary. The diary entries generated 5319 codes and depicted a broad range of everyday experiences. The codes were then grouped under progressively higher-order categories based on similarity of meaning. Only categories with at least two participants reporting were retained.

Figure 6 illustrates the data for responses to the request: "Describe one communication situation that went well today." The Figure's y-axis depicts the number of participants out of 25 who made at least one diary entry associated with a category. Counts are displayed for each hearing aid condition. Figure 7 is parallel to Figure 6, but illustrates the data for responses to the request: "Describe one communication situation that went poorly today." Coincidentally, both qualitative analyses retained nine higher-order categories. In both figures, the most prominent category comprised statements about speech understanding in specific situations. Some statements for positive experiences were: "Can hear better in large staff meeting," and "One on one with a friend – could hear great." Some statements for negative experiences were: "Watching TV missing parts of dialogues," and "Background noise erased my understanding."

Although the data for positive statements (Figure 6) included only one prominent category, there were several prominent categories in Figure 7. In addition to speech perception, these included fairly frequent statements that there were no problems to report, also there were numerous complaints about the quality of amplified sounds. Finally, both figures include categories encompassing the Look-&-Listen and the Speech-Finder programs in the hearing aids, but these had many fewer comments.

The critical importance of speech understanding issues for people with hearing problems is reinforced by the open-ended comments portrayed in Figures 6 and 7. For the purposes of this research, the central concern was whether there appeared to be a difference between basic-feature and premium-feature hearing aids in addressing these issues. This kind of result would be supported by consistent differences favoring the premium-level hearing aids in Figure 6 or penalizing the basic-level hearing aids in Figure 7. Such differences are not present in the data. There is only one category where this pattern is visible: for "all situations" in Figure 6, both premium-level hearing aids performed better than both basic-level hearing aids. A typical statement in this category was “All situations went well”. However, only 6 of 50 potential counts exemplified this outcome. In addition to the overall lack of observable differences between basic-feature and premium-feature hearing aids, it is especially noteworthy that statements addressing the Look-&-Listen and Speech-Finder programs did not substantiate claims of superiority of premium-level technology in everyday life.

Discussion

Our results reinforce other published clinical trials in showing that hearing aids are beneficial [28], and that they improve quality of life [29] for older adults with hearing loss. Additional validation is derived from the categories that were distilled from positive and negative statements about hearing aid functioning in daily life. These categories (speech perception, sound quality, ease of listening, music perception and localization of sounds) are familiar from past hearing aid research.

Typical wearers were somewhat restrained in their estimates of hearing aid merits, awarding a benefit score of about 6 out of 10, and a quality of life improvement score of about 5 out of 7. Nevertheless, it should be understood that for the most part, the participants reacted very favorably to the research hearing aids. Some quotes from typical participants included: “I like the clarity when talking to people,” and “I’m not gonna be happy with my (own) hearing aids when I get finished with all this and go back to ‘em.” It is striking, therefore, that despite the wide net that was cast for outcomes measures, and the meticulous optimization of all the hearing aid fittings, there was no evidence that greater improvements are seen in speech understanding or quality of life when older individuals with uncomplicated, adult-onset, mild to moderate, sensorineural hearing loss used hearing aids with premium technology versus basic technology. Further, the same result was found for both manufacturers tested. In addition, the lack of difference between premium and basic features was seen equally in both new and experienced hearing aid users. It is noteworthy that the experienced subgroup obtained greater benefit from all four hearing aids; however, this is predictable because experienced users typically had more hearing loss than new users.

Because of the nature of null hypothesis statistical testing, it is somewhat difficult to present a convincing case when the finding is one of “not significantly different.” However, as noted earlier on theoretical grounds, a medium effect size is arguably a minimum practically important difference between premium- and basic-level conditions. In our opinion, an effect smaller than this would not be a sufficient basis for systematic clinical recommendations in support of higher cost technologies. The power of the research was sufficient to provide a high probability of a statistically significant result if a medium effect was present, but no statistically significant differences were observed. This finding was bolstered by the fact that, for speech understanding in the laboratory, the 95% confidence interval computed for the overall effect of premium features versus basic features did not encompass or approach a medium effect. In addition, the laboratory findings were further reinforced by consistent data from the questionnaires and the diary entries. Taken together, these findings are quite persuasive. Based on these results, practitioners can feel confident that many older adults with uncomplicated, adult-onset, mild to moderate, sensorineural hearing loss can obtain significantly improved speech understanding and quality of life using modern hearing aids that are programmed, fitted, and fine-tuned according to best-practice clinical protocols. In addition, it appears that basic and premium hearing aid technologies are likely to provide equal benefits under those conditions.

This outcome contradicts many manufacturer product claims and the beliefs of many dispensers. However, it is consistent with extrapolations from the limited body of published independent research that has explored the potential benefit of the types of speech processing applied in the premium models of hearing aids in this research, compared to the basic models. As shown in Table 1, there were four types of features that targeted speech understanding: compression channels, directional microphones, environmental adaptation, and binaural data streaming. The premium version of each of these features is expected to increase speech understanding in daily life relative to the basic version. The rationale, and published research, for each feature is briefly reviewed below.

It is postulated that increasing the number of channels allows amplification to be more precisely targeted to meet the needs of individual patients, and this should improve speech perception. Premium hearing aids are designed with more compression channels than basic hearing aids. However, laboratory studies of persons with mild-moderate hearing loss suggest that optimum performance is achieved with the 4–8 channels typically found in basic hearing aids [30,31]. Further, it has been demonstrated that increasing the number of compression channels can have a negative effect by diminishing important speech identification cues [32].

Single-channel directional microphones in basic hearing aids have been shown to substantially improve understanding of speech in noise in laboratory listening, although improvements are less in daily life [33,34]. Multi-channel directionality is expected to provide independent directional functioning for sounds of different frequencies. Theoretically, this premium feature could boost speech understanding by reducing amplification for unwanted noises of different frequencies that arrive simultaneously from different directions. However, no independent publication was found that compared speech understanding with multi-channel and single-channel adaptive directionality.

In modern hearing aids, analyses of the acoustic environment are used to determine automatic adjustments of hearing aid parameters such as microphone configuration and noise management [35]. The goal is to optimize performance in different listening environments. Premium hearing aid technologies claim to employ advanced sound classification systems that enable more precise adaptation of parameters to further improve speech comprehension in more listening environments. Although there has been some research with this feature [36], none has explored the putative benefits offered by premium environmental adaptation over the basic version.

Simple wireless communication between hearing aids is available in basic hearing aids, but premium hearing aids capitalize on this technology to create real-time binaural data streaming. These algorithms combine inputs from the four-microphone array made available by the dual directional microphones of the two hearing aids. This has the potential for providing more focused front-facing, back-facing, or side-facing directionality. One published laboratory study demonstrated that this premium feature could provide speech understanding benefits compared to basic devices when speech is from behind or the side [37].

As this review reveals, there is very limited independent evidence supporting the superiority of the four premium features over the basic versions of those features. Thus, the results of this investigation are not surprising: when programmed, fitted and fine-tuned using best-practice protocols, the basic and premium hearing aids we used were significantly, but equally, helpful.

Given that new hearing aid models are unveiled by each manufacturer about every 18 months, several newer models of hearing aids have appeared in the three years since this research began. Might the difference in effectiveness of premium- and basic-level features be greater now than it was in 2011? It can be argued that this probably is not the case. Although new products are developed regularly, changes in the technology that underlies each feature typically are small and incremental. Also, as new models are developed, technology designed for premium instruments is relegated to basic-level devices. So, both technology levels tend to improve in tandem over time.

Six manufacturers of high-technology hearing aids accounted for 98% of the world market in 2012 [38]. Our research focused on hearing aids from two of these manufacturers, and both gave the same result. It is reasonable to ask whether the results can be generalized to the four other major manufacturers. We cannot assert that this would definitely be the case. However, it is evident from review of their websites that the various manufacturers maintain a competitive similarity in claims for the features of the products they market. Further research is needed to establish any differences that might exist among manufacturers.

Additional independent research should be considered. Although improved speech understanding is the pre-eminent goal of hearing aid wearers, hearing aid technology also attempts to address other problems of hearing loss and hearing aids such as listening fatigue, poor sound quality, noise annoyance, and diminished localization ability. Research is called for to explore the real-world benefits of premium and basic features for these kinds of outcomes as well. Although our data were obtained using mini-BTE thin tube hearing aids, the same technologies can be housed in other styles (in-the-ear, in-the-canal). Although it seems likely that results with other types of housings would be similar to those we observed, it would be worthwhile to verify that prediction. Lastly, we chose to use a medium effect as the smallest difference between premium and basic features that would be clinically important. It is conceivable that other researchers would argue that a smaller effect size would have practical significance. Research to reveal such an effect would need a larger sample than used in this study.

Conclusion

Modern hearing aids from major manufacturers are remarkably sophisticated devices which can yield substantially improved speech understanding and quality of life for older adults with uncomplicated, adult-onset, mild to moderate, sensorineural hearing loss. However, it cannot be assumed that more technologically sophisticated premium devices will provide greater benefits in daily life than less sophisticated basic devices. The combined laboratory and real-world outcomes in our research are consistent with the conclusion that when hearing aids are programmed, fit and fine-tuned using best-practice protocols, wearers similar to our participants will obtain essentially equivalent improvement in speech understanding and quality of life whether they use basic-level or premium-level feature technology. Because basic-level technology is less costly, benefit per unit cost would be higher for these devices. Therefore, it would be expected that patients will find them to have higher value than premium-level hearing aids. However, it is important for practitioners to keep in mind that the knowledge and skills required to program, fit, and fine-tune modern hearing aids are highly specialized. Professional services that follow best-practice protocols are time-consuming, but they are essential to securing an optimal outcome for each patient, no matter which feature level is recommended.

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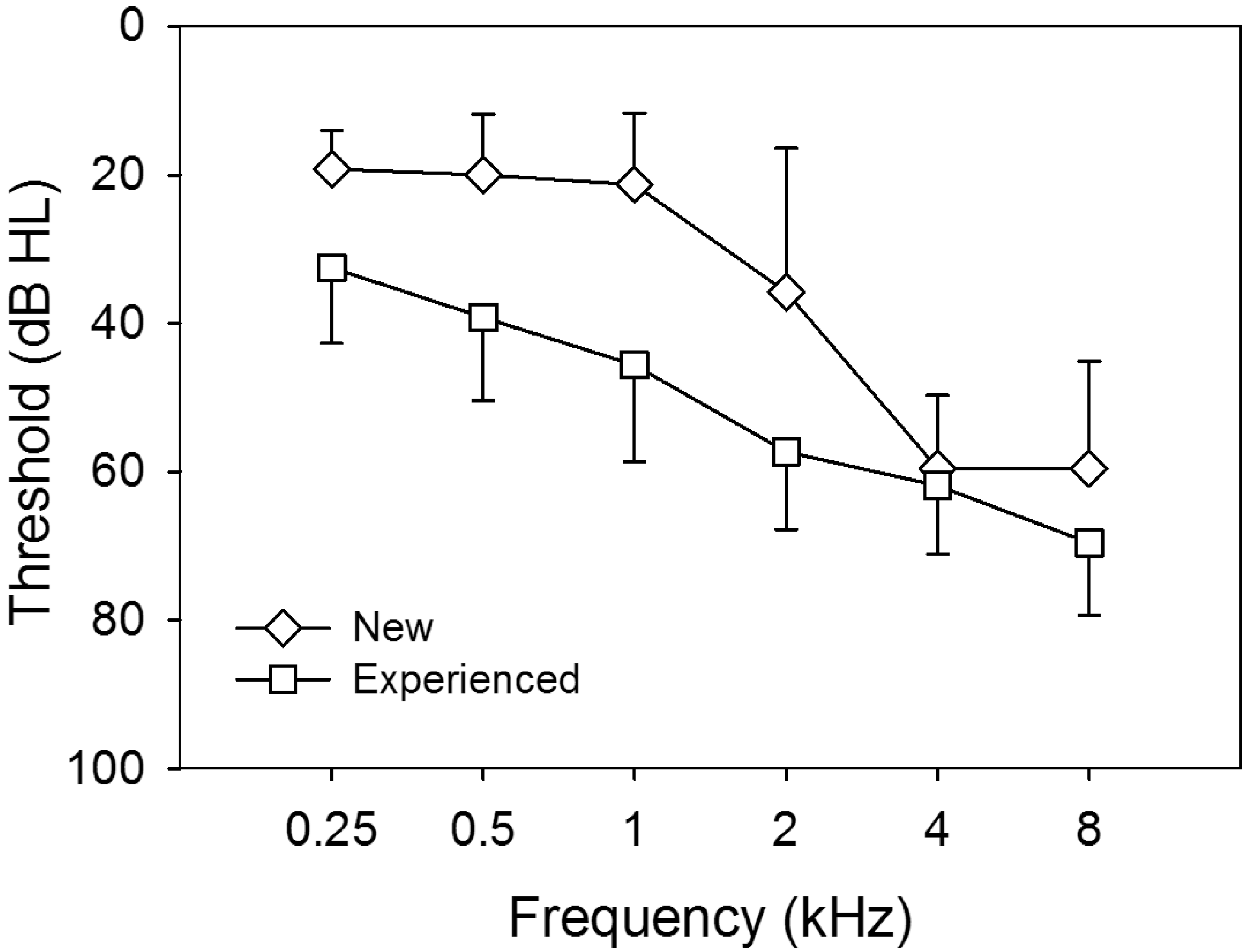

Figure 1.
Mean audiograms for new and experienced hearing aid wearers. Error bars show 1 standard deviation.

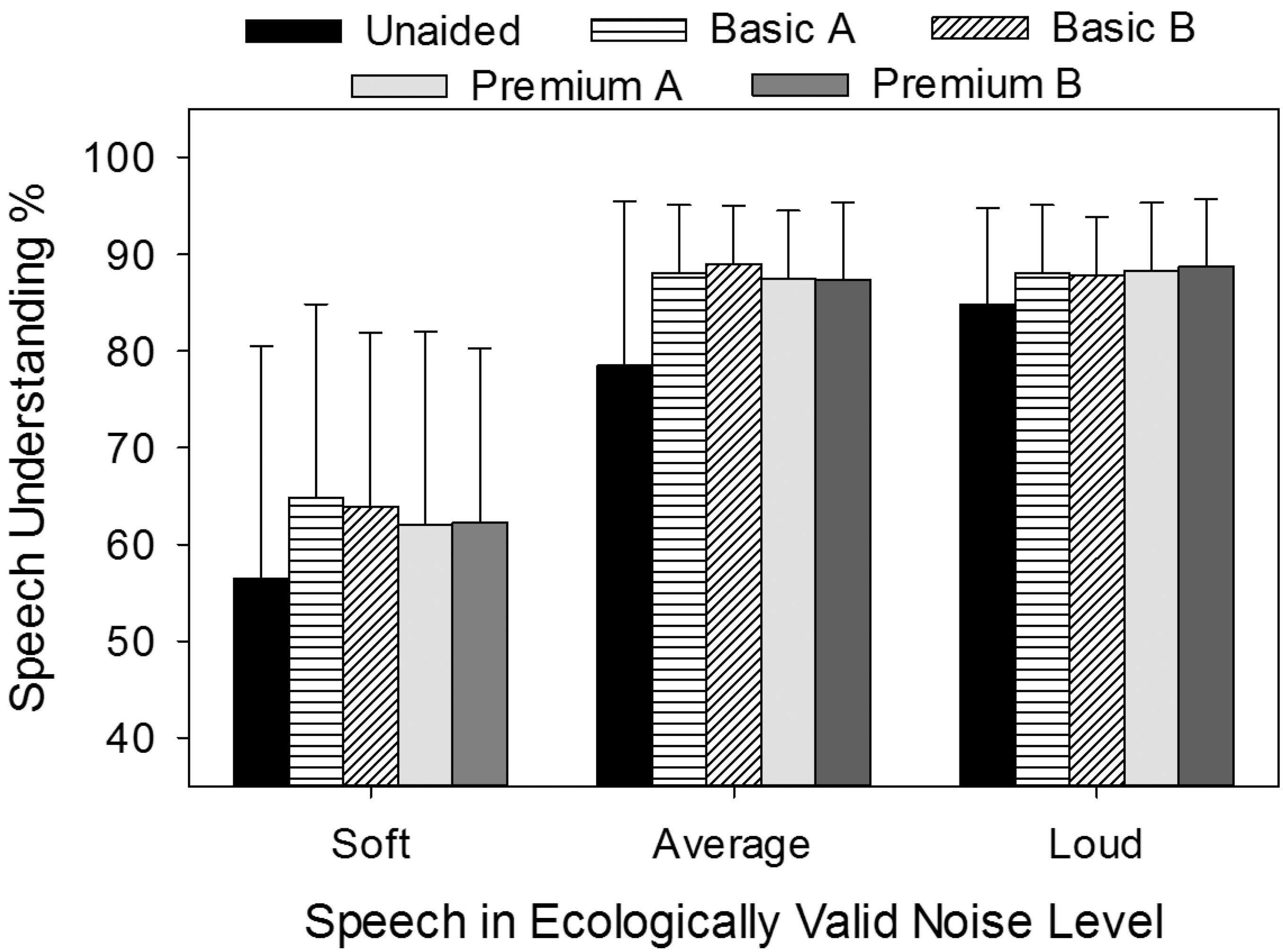

Figure 2.
Mean speech understanding in noise in each condition tested in the laboratory. Data are for listening unaided and with two basic-feature and two premium-feature hearing aids. Error bars show 1 standard deviation.

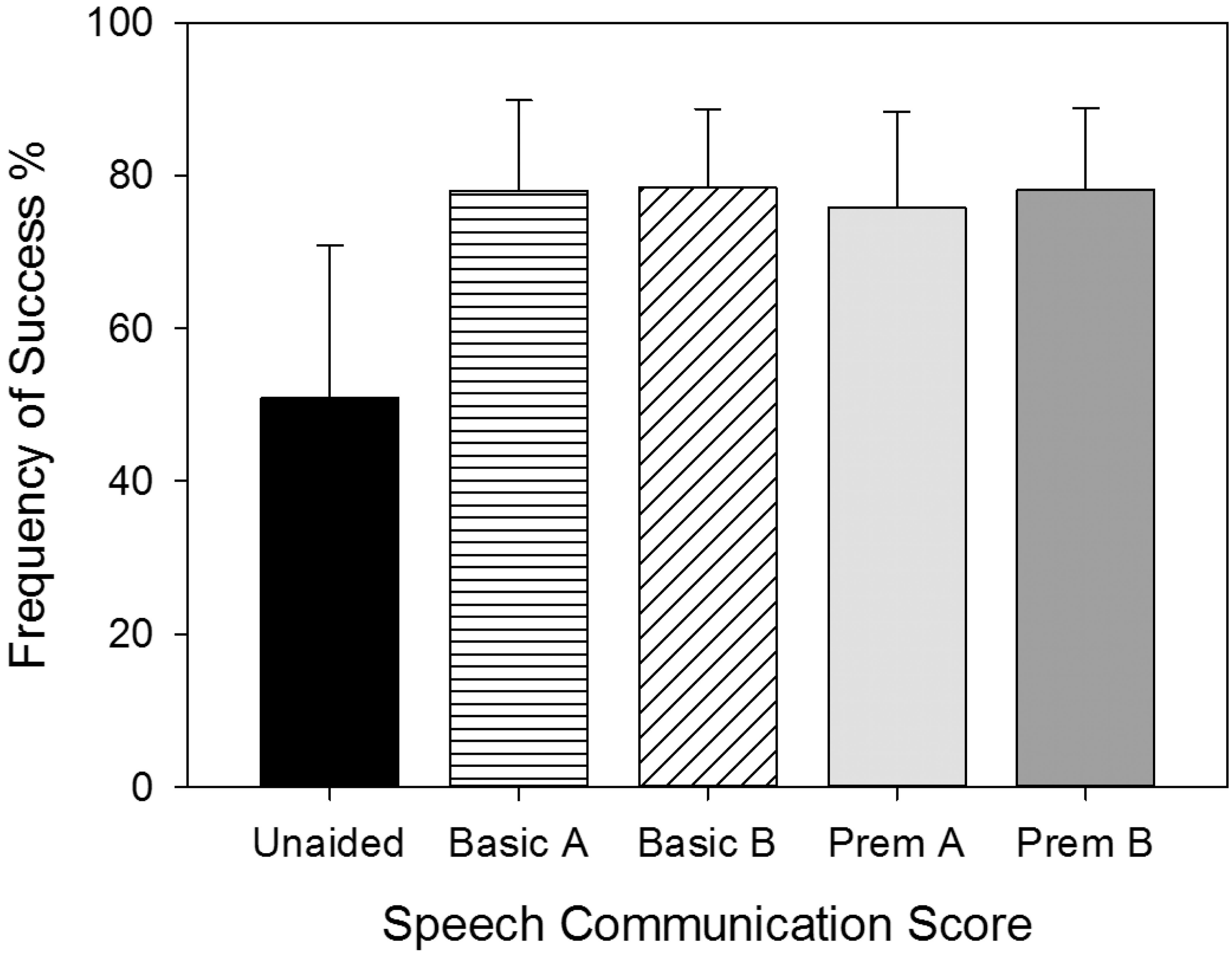

Figure 3.
Mean speech understanding in daily life situations reported on the APHAB questionnaire for unaided listening and listening with two basic-feature and two premium-feature hearing aids. Error bars show 1 standard deviation.

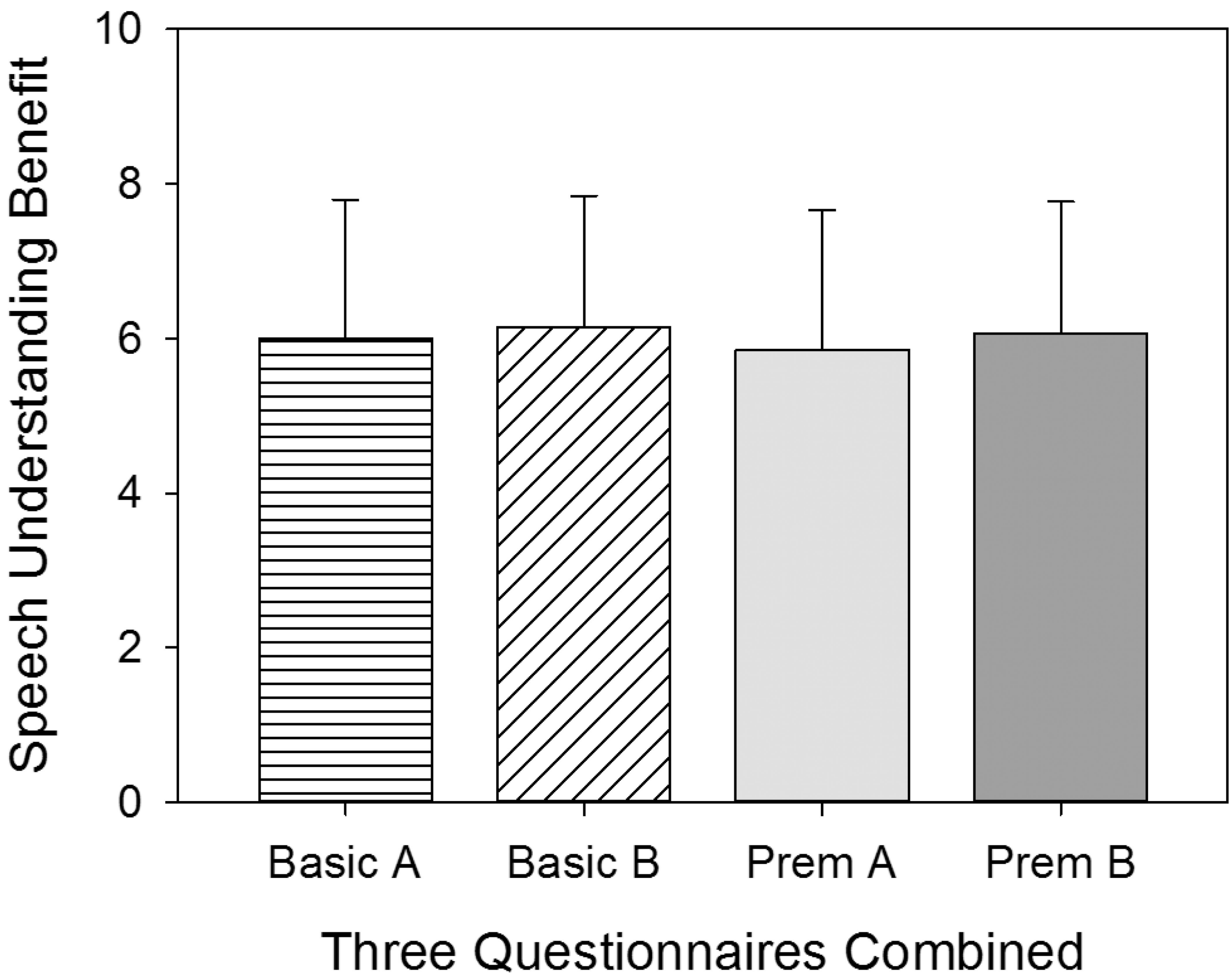

Figure 4.
Mean benefit for speech understanding in daily life situations (three questionnaires combined). Data are for two basic-feature and two premium-feature hearing aids. Error bars show 1 standard deviation.

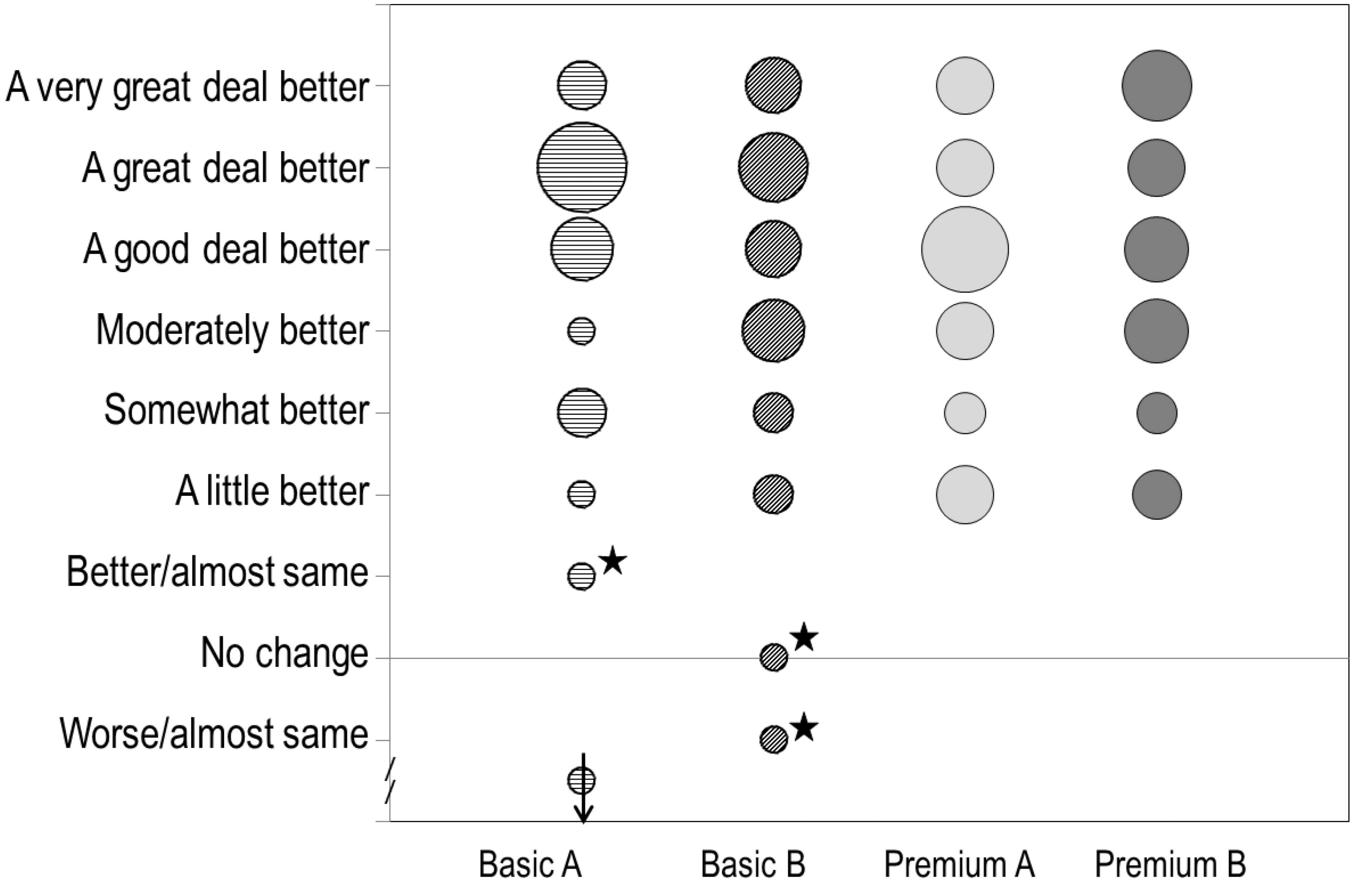

Figure 5.
Change in hearing-related quality of life when using each hearing aid in daily life. The size of each bubble is proportional to the number of subjects who gave that score. The score with the downward arrow was −5, corresponding to “A good deal worse”.

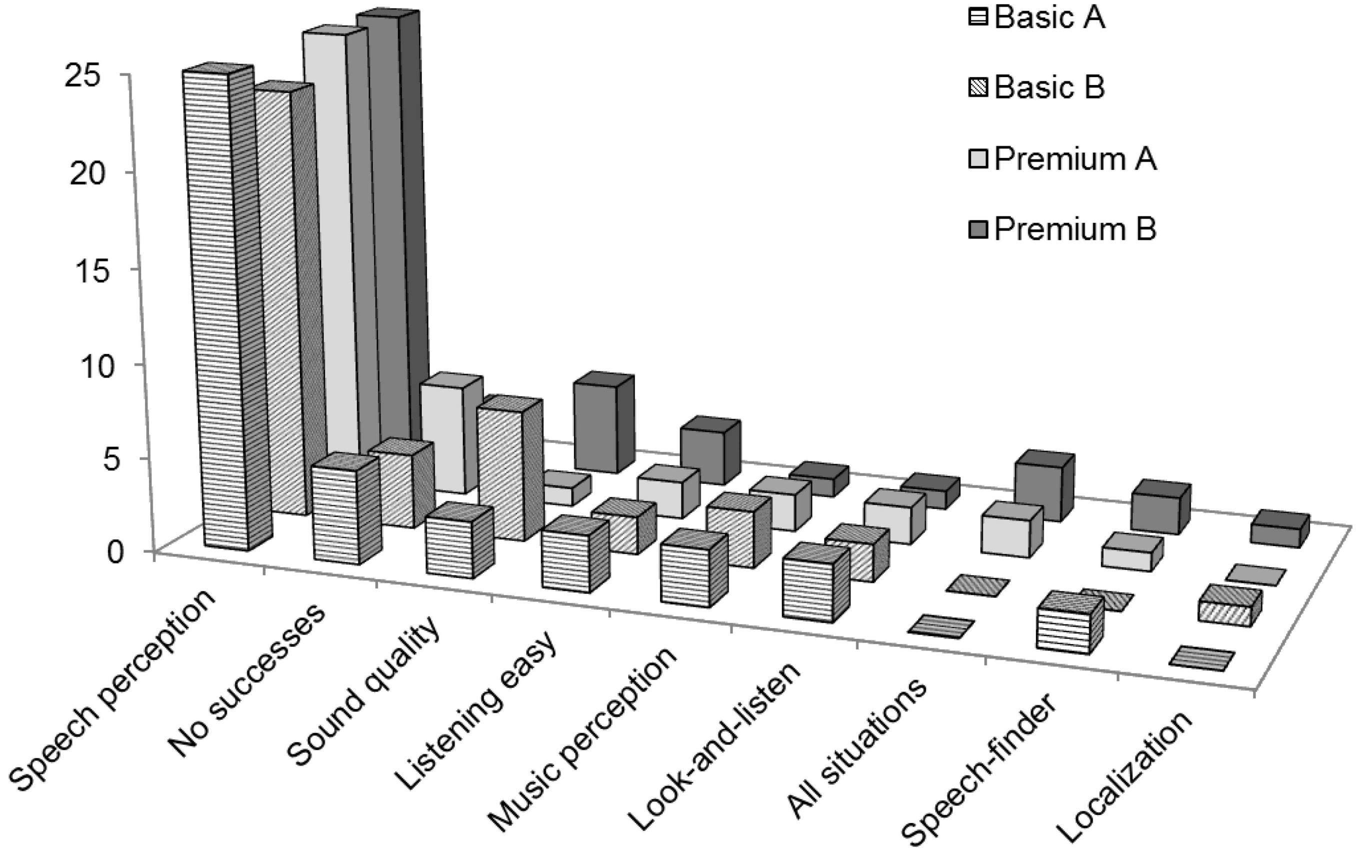

Figure 6.

Everyday experiences that were reported to be positive in daily diaries. The height of each bar gives the occurrences of each topic for each hearing aid. The maximum score is 25.

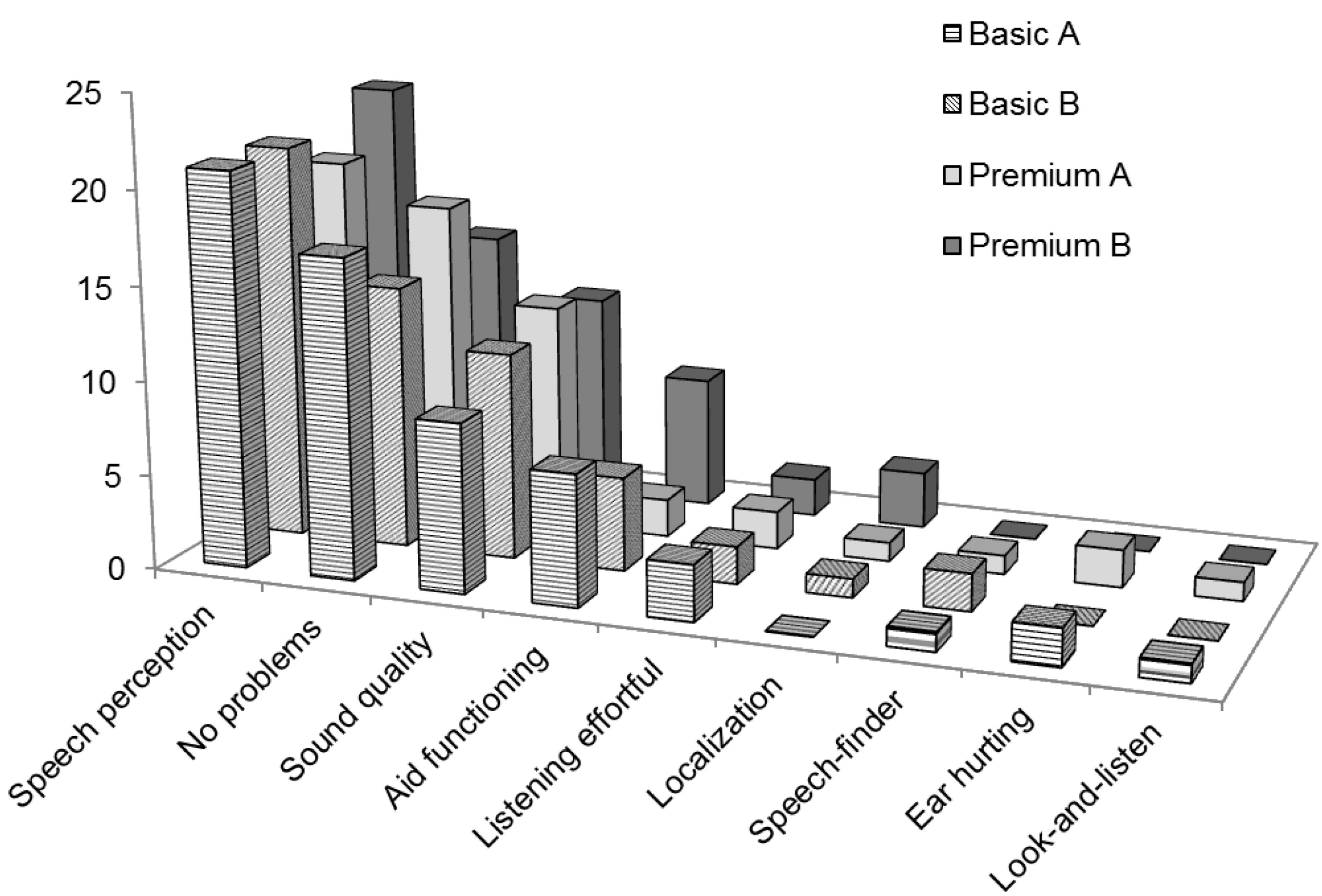

Figure 7.

Everyday experiences that were reported to be negative in daily diaries. The height of each bar gives the occurrences of each topic for each hearing aid. The maximum score is 25.

Table 1

Differences, as described by manufacturers A and B, between basic and premium features in the four research hearing aids. Only features that differed between basic and premium models are included. Features 1–4 are designed to improve speech understanding for the premium model compared to the basic model.

Feature	Hearing Aids			
	Premium A	Basic A	Premium B	Basic B
1. Number of compression channels	16	8	20	6
2. Directional Microphone	Automatic multi-channel adaptive	Automatic single-channel adaptive	Automatic multi-channel adaptive	Automatic single-channel adaptive
3. Environmental adaptation	more	less	more	less
4. Binaural data streaming	yes	no	yes	no
5. Automatic learning of preferred volume	yes	no	yes	no
6. Noise reduction	7 steps	3 steps	3 modes	2 modes
7. Wind reduction	yes	yes	yes	no
8. Reverberation cancellation	no	no	yes	no
9. Impulse noise suppression	3 steps	1 step	yes	no
10. Digital pinna	yes	no	yes	no

Table 2

Mean differences, in dB, at four frequencies, between amplified level and NAL-NL2 prescription targets in the ear canal for each of the research hearing aids. Data for left and right ears were averaged for each participant (N=25). Standard deviations are given in parentheses.

Frequency (kHz)	Hearing Aids			
	Premium A	**Basic A**	**Premium B**	**Basic B**
0.5	−1.9 (2.6)	−1.9 (2.7)	0.5 (4.1)	−0.5 (3.4)
1.0	2.3 (4.5)	2.6 (5.7)	3.5 (5.0)	1.4 (4.8)
2.0	2.2 (4.3)	1.1 (4.9)	4.9 (5.2)	3.3 (4.0)
4.0	−9.1 (5.3)	−7.8 (4.3)	−5.4 (4.0)	−3.4 (4.0)