Utility and Importance of Hearing-Aid Features Assessed by Hearing-Aid Acousticians

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Abstract

Modern hearing instruments include many features addressing situation-specific and user-related amplification. The main tasks of the acoustician are the appropriate choice of hearing instruments and fitting them to hearing impaired individuals. This study aims at investigating the utility and importance of several hearing-aid features as assessed by hearing-aid acousticians. For this purpose, eight different hearing-aid features with three levels each are addressed in a discrete-choice experiment. Preferences for systematically varied combinations of the features are assessed with 143 acousticians, using an adaptive conjoint analysis conducted via the Internet. Based on the preference data, utility and importance of the features are calculated. Highest utility and importance are found for noise cancellation and directional microphones. Outcome of these two features do not differ significantly. In contrast, data management functions, that is, self-learning options, show lowest importance. Though the acousticians' professional experience reveal statistically significant influence on the assessment of some of the features' utility and importance, a clear impact of sociodemographic or subject-specific factors on the outcome cannot be found. The study can be seen as a first approach to determine the estimation of basic hearing-aid features assessed by acousticians. Results show the outstanding utility and importance of features addressing speech perception in adverse listening situations. Furthermore, the outcome reveals reservations of the acousticians regarding self-learning options of the instruments.

Keywords

hearing-aid features, hearing-aid acoustician, utility, importance, discrete choice experiment, conjoint analysis

Introduction

Amplification is the treatment of choice for sensorineural hearing impairment in most cases. Hearing aids address the frequency-dependent loss of hearing sensitivity and dynamics caused by outer hair cell damage and typically include a large number of signal-processing options.

The procedure of obtaining hearing instruments largely varies from country to country. In general, care paths can be separated into public or private systems, or a combination of both. In public systems, hearing-aid provision is conducted by hearing centres that are attached to public hospitals and managed by local authorities. Public systems exist, for example, in Scandinavia and Great Britain. In contrast, in the United States and in most of the countries from Latin Europe as well as Germany or the Netherlands, hearing aids are provided by hearing care professionals who work in the private sector. However, both systems generally imply the collaboration of different professions, such as ENT specialists, audiologists, and hearing-aid acousticians.

The main tasks of the hearing-aid acoustician are choosing, fitting, verifying, and evaluating the hearing aids, and, in the private system, also dispensing the instruments. These issues are complex and modern hearing instruments contribute much to this complexity since they allow for the choice of a large number of different features that help to minimize hearing problems within different listening situations. For instance, most hard of hearing people exhibit significant problems in noisy listening environments (e.g., Brooks & Hallam, 1998;

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Turner, 2006), and features addressing these situations reveal high utility for the hearing-aid user (Meister, Lausberg, Walger, & von Wedel, 2001). Hearing aids, therefore, include algorithms such as noise cancellers that analyze the incoming sound and try to suppress noise components of the signal as well as beamformers that use spatial microphone characteristics to attenuate unwanted sounds. As a rule, hearing aids have different listening programs that can be switched manually or automatically in order to adapt amplification for different listening environments. Other important aspects are the use of telephones or additional devices such as audio systems. Furthermore, data management options might help to fit the aids more specifically to the needs of the individual. Data logging stores the different adjustments that are made while using the hearing aids, and data learning attempts to use this information for self-adaptation of the instrument.

These features are important issues for the acoustician in several ways. First, it is important that the hearing-impaired user gains maximum benefit from the instrument. Since individual hearing loss as well as individual demands and needs vary greatly, the appropriate choice of features is an important issue. Second, the procedure of fitting the instrument and adjusting or using these features is crucial. For instance, are the procedures easy to handle or time-consuming? Are the modifications comprehensible and reproducible? Furthermore, at least in the private system, economical issues are important because the acoustician dispenses the instrument to the client and also provides service routines. These aspects might be important for future hearing-aid developments. Thus, acousticians' estimation of the utility and importance of different hearing-aid features is, therefore, worthy of investigation.

To our knowledge, utility and importance of hearing-aid features as assessed by hearing-aid acousticians have never been examined. The present study can be seen as a first approach at closing this gap. It is based on a discrete-choice experiment conducted via the Internet with hearing-aid acousticians in German-speaking European countries.

Methods and Subjects

Discrete-Choice Experiments

In discrete-choice experiments (DCE), pairs of options are presented to the respondents, and their preference for one over the other is elicited. Conjoint analysis (CA) is a common method used within DCE. It is based on systematically varying the features and associated levels of the options. Concretely spoken, different hearing-aid features and levels (see Table 1) are combined, and preferences for these combinations are assessed.

CA was developed for mathematical psychology and marketing research and is widely used in health care sciences (e.g., Ryan & Farrar, 2000; Ryan, Major, & Skåtun, 2005). In contrast to compositional preference measurement methods such as rating or ranking the utility of different features separately, CA has several advantages. First, the discrete-choice

task resembles a real choice situation for the respondents, which is a key distinction from compositional measurement (Green, Goldberg, & Montemayor, 1981). Instead of isolated features, product profiles are presented. The test participants' task is to rate the preference for one product profile. This approach does not directly assess the importance of the features but allows for calculating the contribution of each feature and its different levels to the overall preference judgement. Furthermore, CA considers trade-offs between the tested features. By means of the preference judgements, metric data for the importance of the features and utility of the levels can be determined (Louviere, Hensher, & Swait, 2000).

In the present study, an Internet-based adaptive conjoint analysis (ACA, Sawtooth Software Inc. V. 6.4) was used. Unlike CA, which is based on presenting a predefined set of stimuli, ACA is not a static procedure but continuously considers the respondents' answers that are used to generate individually tailored stimuli within the current experiment. In detail, subsequent to presenting three options, the following three options are generated on the basis of the data collected so far. All in all the participants had to make 18 choices. The striking advantage over CA is the much higher efficiency in presenting higher targeted stimuli to evaluate individual preferences. As a consequence, ACA allows considering more features and levels, respectively, than CA.

Conducting an ACA includes four steps. First, the features characterizing the product to be examined have to be chosen. For example, an important hearing-aid feature might be the option of using of directional microphones. For each feature a list of mutually exclusive levels has to be established (see Table 1). Following the example above levels might be fixed on adaptive directional microphone characteristics. This most basic step is usually established by the professionals designing the ACA. The next step is a rating of the preference for the levels separately for each feature considered. This is followed by a conjoint pairwise comparison of hypothetical "products" based on different feature and level combinations by presenting trade-off questions (i.e., "Which combination do you prefer?"). In order to restrict complexity, only a subset of all the features used is shown for any given question (usually two or three features). Based on the preference statements for the hypothetical products, utility of the levels (so called part worth) and importance of the features can be calculated using ordinary least squares (OLS) estimation (Orme, 2009). The calculations yield interval-scaled data for the utilities and ratio-scaled data for the importance.

Features and Levels

One constraint that CA methods reveal is the number of features and levels considered. The theoretical number of potential stimuli can be described as l^f whereas l is the number of levels and f is the number of features. Though this theoretical number is significantly reduced in ACA, it did not seem viable to assess more than eight features with three levels each

for the present study. In order to avoid any unwanted bias the number of levels should be balanced across features as features with more levels tend to elicit greater importance. Another constraint is that possibly complex features have to be conveyed by brief, comprehensive descriptions yielding simplified models of real products or services.

Considering these possible limitations the features and levels were determined in a pilot study. Ten hearing-aid acousticians from different institutions were asked to nominate important hearing-aid features. These features were combined with different levels and were used to compose stimuli for the discrete-choice experiment. Another 10 acousticians were asked to judge these combinations. Based on their comments, the features and levels were modified until the resulting stimuli were agreed by consensus between the authors and the acousticians. A brief explanation was given with the features in the survey. The chosen features and levels are given in Table 1.

Preference Rating for the Levels

Prior to pairwise comparison of the stimuli a preference rating for the levels of each feature was conducted. This rating is used to combine features and levels to create different stimuli tailored to each individual respondent. An example is given in Table 2. The task for the participants was to rate their preference for each level using a 5-point scale.

Pairwise Comparisons

Based on the preference ratings individual stimuli were presented. This is the core of CA in general. The respondents' task was to state his or her preference (i.e., prefer A, prefer B, both are equal) for one of the stimuli in a competitive manner. An example is given in Table 3.

Up to three different features were combined. The participants were asked to make a trade-off, with all the other features being considered equal. For assessing the reliability of the participants' answers, a control stimulus was included that had solely monitoring purposes and did not affect the outcome. The outcome for this stimulus was highly predictable since it contrasted three features with low levels (i.e., noise cancellation: none, audio-in: none, listening programs: 1) with the same features with high levels (i.e., noise cancellation: adjustable, audio-in: wireless, listening programs: 3, automatically selected). Subjects who rated this control stimulus in an unexpected manner (to prefer the combination with low levels) were not considered in the analysis of the data, since it was possible that they did not understand the task of the experiment correctly or that their responses were spurious or unreliable.

Respondents

The study was announced in several print media, such as the newsletter of the "Bundesinnung der Hörgeräteakustiker

Table 1. Features and Levels Considered With the Conjoint Analysis

Feature	Levels
<i>Audio-in options</i> (measures to connect audio devices such as MP3 player, etc.)	None Via wire Wireless.
<i>Binaural hearing aids</i> (communication between two aids)	None Semi (synchronization of two instruments with regard to, for example, switching programs, volume control) Full (exchange of audio data, for example, for better sound localization and speech segregation)
<i>Data management</i> (collection and application of client-specific data such as loudness adjustments)	None Data logging (collection) only Data logging plus data learning (automatic adjustment)
<i>Directional microphones</i> (use of beamforming for better speech understanding in noise)	None Fixed directional microphone characteristics Adaptive directional microphone characteristics
<i>Listening programs</i> (number and selection of situation-specific programs)	1 program only 3 programs selected manually 3 programs selected automatically based on classification algorithms
<i>Noise cancellation</i> (one-microphone algorithms based on audio-signal analysis in order to improve speech intelligibility in noise)	None Fixed Adjustable (e.g., smooth, medium, intense).
<i>Telephone options</i> (measures to improve use of telephones and mobile phones with the hearing instruments)	None Manually switched t coil T coil activated automatically if telephone headset is held close to the hearing aid
<i>Wind-noise cancellation</i> (suppression of noise caused by wind turbulences)	None Fixed Adjustable (e.g., smooth, medium, intense).

(BIHA),” which is the umbrella organization of acousticians in Germany, and the “Hörakustik,” which is one of the most frequently read trade magazines in the German-speaking hearing-aid industry. In total, 170 hearing-aid acousticians participated in the experiment. Twenty five of them did not complete the survey. Another 2 participants were excluded following the control stimulus criterion yielding 143 useable data sets. The survey was conducted online. To participate an identification and password that were given with the announcements were required. Participants were characterized with respect to different user-specific data that were elicited at the end of the survey (see Figure 1).

Table 2. Example of a Preference Rating for the Feature “Directional Microphones”

Directional microphones	Extremely undesirable	Undesirable	Intermediate	Desirable	Extremely desirable
None					
Fixed					
Adaptive					

Table 3. Example of a Pairwise Comparison With Three Features

Stimulus A	Stimulus B
Directional microphone: <i>fixed characteristics</i> Audio-in: <i>wireless</i> Data management: <i>none</i>	Directional microphone: <i>adaptive characteristics</i> Audio-in: <i>by wire</i> Data management: <i>data logging</i>

Figure 1. Demographic and user-specific data of the respondents. Values are given in % ($n = 143$). Supraregional medium: less than 40 chain stores, supra-regional large: 40 or more chain stores, urban medium: 30,000 to 100,000 habitants, urban large: more than 100,000 habitants.

Results

From the outcome of the discrete choice experiment, interval-scaled data for utilities can be calculated. Utilities were normalized to values between 0 and 1, with 1 representing the highest part-worth utility (i.e., adjustable noise canceller). Figure 2 displays part-worth utilities for the features examined,

averaged across all participants. Largest utilities can be seen for the feature “noise canceller” and “directional microphones.” Even simple implementations (fixed) that are currently standardized and no longer considered novel features of modern hearing instruments reveal relatively large utility. Utility further increases with more sophisticated solutions (adjustable, adaptive). The feature “binaural hearing aid” also reveals high utility, but the increase from “none” to “semi” is larger than from “semi” to “full.” The opposite pattern can be observed with “audio-in” where the difference between the lowest and the medium level (“none” vs. “wire”) is relatively small, but the change from “wire” to “wireless” shows a larger increase in utility. The results for “data management” are especially interesting since it is the only feature where the highest level (“logging and learning”) does not show higher mean utility than the medium level (paired t test, $p = .3$).

Note that due to the arbitrary dummy coding within each feature it is not possible to directly compare different levels across different features. Moreover, due to the nature of interval-scaled data, it cannot be assumed, for example, that a value of 1 has double the utility of 0.5.

This is different when importance values are considered. Relative importance emerges from the range of part-worth utilities within the different features and yields ratio-scaled data. Figure 3 depicts the relative importance of the features averaged across all subjects. According to the part worth utilities, noise cancellation is the most important feature followed by directional microphones. When conducting multiple comparisons with α -adjustment ($p = .05/29$) the difference between these two features is not significant (t test for matched pairs, $p = .237$). However, these two features are significantly more important than all other features ($p < .0001$). Importance of these two features was followed by “binaural hearing aids,” “programs,” “audio-in,” and “wind-noise canceller” that revealed relative values larger than 10%. “Telephone options” and “data management” showed the least importance. The importance of “data management” was significantly lower than “audio-in” ($p < .0001$), “programs” ($p < .0001$), and “binaural hearing aid” ($p < .0001$). The importance of “telephone options” was significantly lower than “binaural hearing aid” ($p = .001$).

In order to examine whether the demographic and user-specific data had influence on the outcome of the discrete-choice experiment, a multivariate analysis of variance (MANOVA)

Figure 2. Normalized utilities of the hearing-aid features and their levels. Data are averaged across all participants. Error bars show standard deviations.

Figure 3. Relative importance of hearing-aid features averaged across all participants (mean and standard deviations).

was conducted for the utility values. The only factor that significantly influenced the outcome was professional experience (Wilks-Lambda, $p = .013$). Tests of between-subjects effects revealed that utilities for noise cancellation (difference between levels “none” and “adjustable,” $p = .029$), data management (difference between levels “none” and “logging and learning,” $p = .043$), and wind-noise cancellation (differences between levels “none” and “fixed,” $p < .001$; “fixed” and “adjustable,” $p = .004$) showed significantly different results depending on the four groups considered with professional experience. Figure 4 shows the utilities for these three features. However, post hoc Bonferroni-tests with α adjustment ($p = .05/6$) showed statistically significant differences only between groups E1 (experience < 6 years) and E4 (>20 years) for no noise cancellation and adjustable noise cancellation and between groups E2 (6-10 years) and E4 and groups E3 (11-20 years) and E4 for no wind-noise cancellation and fixed wind-noise cancellation, as well as between-groups E1 and E3 and groups E3 and E4 for fixed and adjustable wind-noise cancellation.

Discussion

The aim of the study was to estimate the utility and importance of different hearing-aid features as assessed by hearing-aid acousticians. In addition to the demands of hearing-impaired persons the acousticians’ opinions might also be an important indication for the choice and design of features in future hearing aids. The data presented herewith can be seen as a first approach to address this issue. Though all major hearing-aid dispensers in German-speaking countries participated in the study, the sample is relatively small and, thus, might not be representative for hearing-aid acousticians in general. However, demographic data revealed a broad spectrum of backgrounds, and some interesting findings emerged that are worthy of discussion.

Figure 4. Normalized utilities for noise canceller, wind-noise canceller, and data management with respect to groups of different professional experience (E1: <6 years, E2: 6-10 years, E3: 11-20 years, E4: >20 years).

The ACA approach applied in this study is highly valued in product-specific research and has several important advantages over conventional judgment methods. It offers the possibility to evaluate products with several features and levels allowing a trade-off between product features (Green et al., 1981). Moreover, discrete-choice experiments are increasingly used in health sciences (Ryan, 2004), including topics

related to hearing-aid provision (Grutters, Joore, Kessels, Davis, & Anteunis, 2008; Grutters et al., 2008; Meister et al., 2001). Nevertheless, some constraints should be considered when interpreting the data. First, real hearing instruments include many more features than those considered within the experiment, but a complete investigation of all possible combinations is obviously not possible. Completing the discrete-choice experiment required on average about 10 to 15 min, which in our opinion is at the upper boundary of what is a reasonable amount of time for a survey on a voluntary basis. Second, characterizing the levels of the features in detail within such a survey is somewhat restricted, yielding reduced complexity of the stimuli. Nevertheless, utility and importance of the features generally can be mapped by the method (Louviere et al., 2000). Another constraint might be the level of familiarity the acousticians had with the different features presented. One could argue that different experience with the features could cause a bias in the estimation of utility and importance. Consequently, only features and levels with similar familiarity for the respondents had to be considered. This might be appropriate to determine the current state of hearing instrument technology. Evaluating the design of new products to maximise utility is more demanding, since they inevitably combine both existing and novel features. There will obviously be limited experience with newer features. This issue is nevertheless important and falls within the scope of this study. Thus, it was decided to consider existing and novel features and to examine how they were assessed in relation to each other.

The results revealed that features addressing the improvement of speech discrimination in adverse listening situations clearly gained highest utility and importance. Both noise cancellation and directional microphones yielded high utility even for intermediate levels (fixed) that further increased for more topical levels (adjustable/adaptive). Importance of these two features did not differ significantly from each other, showing that the acousticians do not have a preference for one of the two strategies. This seems reasonable since both features address different aspects. Noise cancellation algorithms attempt to ameliorate listening in situations where essentially stationary noise is present, whereas directional microphones are used to enhance the understanding of speech, for example, against a multitalker background. A study based on similar methods conducted with hearing-aid users also revealed that features addressing these situations were of highest importance (Meister et al., 2001). It was shown that relative importance of speech discrimination in noise within a set of six hearing-aid features was close to 30% and that it even increased when considering a subgroup of younger hearing-aid users (mean age = 45 years).

In the present study the importance of noise cancellation and directional microphones was significantly higher than that of all other features considered. However, the feature "binaural hearing aids" also gained high importance. This

feature addresses the communication between two instruments fitted to the right and left ears of an individual and involves a number of potentially useful functions and has strong prospect regarding the design of new hearing instruments. A technique that has recently been included in hearing aids allows for synchronization of the adjustments such as listening programs, volume settings, and so on. In our study it was addressed by the intermediate level ("semi") of the feature and yielded high utility compared to hearing instruments without binaural options. "Full" binaural hearing aids are still the subject of research though first implementations are available with the latest commercial instruments. "Full" binaural processing is based on the exchange of audio data between the devices and aims to restore the abilities of the healthy binaural system with respect to spatial hearing or separation of signal and noise sources (Boothroyd, 2006; Kollmeier & Koch, 1994; Mencher & Davis, 2006). Compared to the level "semi," "full" binaural hearing aids gained a significantly higher utility. Nevertheless, considering the outstanding abilities of the healthy binaural system one might have expected an even higher utility of the "full" processing option. Thus, it might indeed be the case that the acousticians' assessment of this level was conservative because of limited experience. On the other hand, the acousticians might be aware of the large computational expense involved in "full" binaural processing and the fact that it is not possible to completely restore the abilities of the healthy binaural system to date. Consideration of these aspects might also be an explanation for the fact that the assessment was more reserved than it might otherwise have been. Nevertheless, importance and utility data clearly show that binaural hearing instruments have considerable potential.

The feature "listening programs" considered a different number of programs as well as manual or automatic selection. As expected, three programs had significantly higher utility than only one and the option of automatic program selection based on classification algorithms showed significantly higher utility than manual selection.

With the feature "audio-in" it was found that wire-based connection of additional devices such as CD players had only a marginal, albeit significant, higher utility than external sources with no connecting options. In contrast, utility of wireless connection was clearly higher. This reflects the fact that wireless connections are state of the art in modern hearing instruments.

Similar to "noise canceller," the feature "wind-noise canceller" also showed increasing utility with more complexity of the levels from fixed to adjustable processing. With the "telephone options" it was found that automatic t-coil switching showed only marginal higher utility than manual switching that was in turn clearly superior to no-telephone options.

The assessment of the feature "data management" is noteworthy since it was the only feature that did not exhibit significantly higher utility for the highest level (data logging

plus data learning) compared to the intermediate level (data logging). Data logging involves the option of storing user-specific settings that might be used by the acoustician for fine-tuning purposes. Data learning reflects the option of self-adaptation of the instrument with respect to the user-specific situations and adjustments. Since self-adaptation is based on the data stored it was decided to combine these two options for the highest level. Unsurprisingly, data logging had significantly higher utility than no-data management options. In contrast, utility of data logging compared to data logging plus data learning was about the same. That is, storing user-specific data was found to be a useful tool, but the option of self-adaptation did not provoke extra utility for the “average” acoustician. We can only speculate about the reasons for this finding: The acousticians may lack trust in the function of self-adaptation, or they may even regard it as a potential threat to their role in the fine-tuning of hearing instruments.

Another interesting question is whether perceived utility of the different features and levels depended on the demographic and subject-specific data recorded with the survey. Indeed, we found statistically significant differences of the utilities with respect to the acousticians’ degree of professional experience. This held true for the features “noise canceller,” “wind-noise canceller,” and “data management.” However, when computing post hoc tests significant differences could only be observed for some specific group comparisons and were thus relatively unsystematic and difficult to explain, or they were systematic (as with “data management”, see Figure 4) but failed statistical significance. Hence, it could not be proven that any of the additional factors considered with this study had consistent impact on the acousticians’ assessment of utility and importance of the hearing-aid features.

In conclusion, the study showed that features addressing speech understanding in adverse conditions revealed highest utility for the acousticians and, thus, were of greatest importance. Even simple applications such as directional microphones with fixed characteristics showed high utility. These results can be explained by the fact that hearing-aid users still frequently complain about difficulties in understanding speech in noise (e.g., Bertoli et al., 2009; Brooks & Hallam, 1998; Turner, 2006) while at the same time understanding in these situations are of high importance for them (Meister et al., 2001). Thus, further development of strategies and algorithms addressing listening-in noise and cocktail-party situations will continue to be an important topic. In connection with this, the potential utility of binaural hearing aids is obvious. The judgement of data management options should be noted since the acousticians showed clear reservations with respect to data learning that enables self-adaptation of hearing instruments.

Based on these findings, further investigations might consider more detailed levels of the features found to be important

for the acousticians as well as economical aspects such as retail prices or subsidiaries that also play a significant role for both the hearing-aid user and the hearing-aid dispenser.

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