Hearing aid feature profiles: The success of rehabilitation

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We recently developed a method to objectively classify hearing aids, using technical data (e.g., compression, noise reduction, etc.) from over 3900 different devices. This yielded hearing aid subgroups called ‘modalities’, that were characterized as distinct feature profiles, independent of manufacturer or type. Our present study aims to combine these objectively defined modalities with audiologically relevant rehabilitation needs, using data including audiological diagnostic tests and two questionnaires for subjective ratings. We investigated which hearing aid modalities contribute to successful rehabilitation results, and to which extent these modalities can be associated with specific rehabilitation needs. Our results indicate that more adjustable hearing feature channels or levels do not necessarily lead to better rehabilitation results.

INTRODUCTION

The choice of a hearing aid that covers the rehabilitation needs of a hearing-impaired person is an important starting point for a successful rehabilitation. This study combines technical hearing aid data based on publicly available information (e.g., hearing aid datasheets) with user data that includes the individual rehabilitation needs of the hearing impaired. The user data consists of various measures, such as audiogram, demographical data, and subjective data. The hearing aid data used in this study was made independent of brand or manufacturer using previously defined subgroups of hearing aids, based on a clustering of hearing aid features (Lansbergen and Dreschler, 2020). The resulting subgroups of hearing aids, referred to as ‘modalities’, were characterized by particular profiles, representing the complex interplay between the selected hearing aid features.

This study is a first step in using hearing aid modalities as a selection tool to achieve successful hearing aid rehabilitation at group level. We consider the combined effects of hearing aid features by investigating the effects of modalities rather than isolated features on user perceived benefit.

METHOD

Two datasets were used in this study. One dataset with user data on hearing aid rehabilitation, and a second dataset on technical data from hearing aids. User data were collected between 2015 and 2017 during the regular hearing aid rehabilitation process in the Netherlands, including both new and experienced users. Hearing aid selection was always done by an audiologist or dispenser, where the professional

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ideally presented a choice of two or more hearing aids to the patient. Subjects assessed their hearing aid rehabilitation process before and after a trial period, that included selection and fitting of a hearing aid. They were asked to evaluate perceived benefit based on personal rehabilitation goals and the degree of auditory disability. For this subjective evaluation two questionnaires were used: the Client Oriented Scale of Improvement (COSI) by Dillon *et al.* (1997) and a slightly adapted version of the Amsterdam Inventory for Auditory Disability and Handicap (AIADH), called AVAB[1]. COSI evaluates personal rehabilitation goals by measuring the degree of change (DC) and the final ability (FA) due to the hearing aid fit. AVAB evaluates predefined listening conditions before and after the hearing aid fit on six dimensions of auditory disability[2]. AVAB post-evaluation results could be thought of as a measure of FA, similar to the FA of COSI. Likewise, the difference between AVAB item scores prior to the hearing aid fit and post hearing aid fit, could be thought of as a measure of DC. To estimate AVAB DC measure, differences between pre- and post-AVAB were normalized based on the ratio of the actual pre- and postscore difference and the maximum possible difference (maximum benefit is 100%)[3].

Each of the 32 AVAB questionnaire items were related to one of six dimensions of auditory disability: detection of sounds (Det), sound discrimination (Dis), auditory localization (Loc), speech in quiet (SiQ), speech in noise (SiN), and noise tolerance (Tol). This resulted in mean AVAB scores per dimension of auditory disability, and overall mean AVAB scores. Personal COSI goals were matched to one or more dimensions of auditory disability (Dreschler and de Ronde-Brons, 2016), consequently, mean COSI scores for the dimensions of auditory disability could also be obtained (Lansbergen *et al.*, 2018).

Hearing aid modalities

The hearing aid data contain technical information of hearing aids, such as the number of compression channels, and were available on the Dutch market in March 2018. Data was provided by the manufactures through their hearing aid datasheet and was checked by a group of audiologists. After a selection procedure, data from 2106 behind-the-ear (BTE) hearing aids were included, containing all major, but also some lesser known, hearing aid manufacturers. The selection relied on the following criteria: (i) no missing data and (ii) no ambiguity (i.e., conflicting technical details).

The dataset contained about 50 of the most important characteristics of a hearing aid. After applying a data processing procedure, a set of 10 key hearing aid features were identified as relevant for audiological rehabilitation and were used as input for

[1]The original version of AIADH was developed by Kramer *et al.* (1995), details on the used AVAB questionnaire could be found in Dreschler and de Ronde-Brons (2016).

[2]Kramer *et al.* (1995) defined ‘auditory disability’ as the difficulties experienced in everyday hearing.

[3]This research used the same data as described by Lansbergen *et al.* (2018). A more detailed description of the specific data gathering methods of the user data can be found in their paper.

further analysis (Lansbergen and Dreschler, 2020). The latter was done using Latent Class Tree Analysis (van den Bergh *et al.*, 2017), which is an extension of the better known Latent Class Analysis clustering method. Using this method, we extracted six mutually exclusive hearing aid modalities from the hearing aid data, see Figure 1.

Statistical analyses

Computation of mean COSI scores for the dimensions of auditory disability resulted in missing data for one or more dimensions. We therefore used a linear mixed-effect model on the COSI and AVAB scores because such models allow unequal variances and can accommodate unbalanced data. The type of hearing aid modality was used as between-subject factor and the type of auditory disability dimension as within-subject factor. Complementary post-hoc analysis was done using the Games-Howell pairwise multiple comparison procedure, because this procedure can accommodate unbalanced group sizes. Cohen's *d* was computed to examine the effect sizes between hearing aid modalities that showed significant differences on the post-hoc analyses.

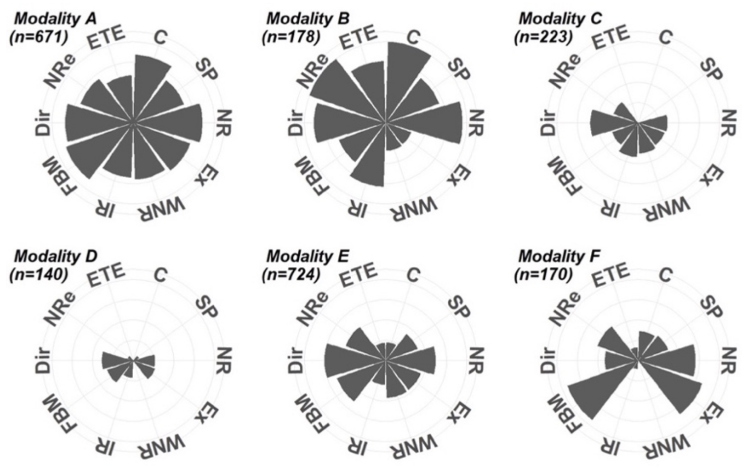

Figure 1: Six mutually exclusive hearing modalities, for behind-the-ear type hearing aids. The modalities were defined by ten hearing aid features: (C) compression channels; (SP) sound processing channels; (NR) noise reduction levels; (Ex) expansion levels; (WNR) wind noise reduction levels; (IR) impulse reduction levels; (FBM) feedback manager; (Dir) directionality type; (NRe) Noise reduction environments; (ETE) ear to ear communication type. The values on the radar chart represents mean features measures (i.e. data rescaled between 0 and 1). The n-values indicate the number of unique hearing aids associated with the modality.

RESULTS

User data from 1149 subjects were included. Because the hearing aids that were used for rehabilitation were known for each subject, user data could be merged with matching hearing aid data, including the corresponding modality. Only a small number of subjects were fitted with in-the-ear type hearing aids (29 subjects) and were excluded from the data. Remaining subjects were all fitted with a behind-the-ear type hearing aid. The mean age of the included subjects was 67.7 years (SD ± 13.2 years, range: 20-98 years). The weighted binaural hearing loss for 0.5, 1, 2 and 4 kHz were calculated using the average values of the better ear and the worst ear in a ratio of 5:1, considering that overall hearing disability is mainly determined by the better hearing ear in subjects with asymmetric hearing loss. The mean binaural hearing loss of all subjects was 45.3 dBHL (±14.6 dBHL). Mean DC and FA scores for COSI and AVAB are shown in Table 1, along with the distribution of matched modalities. The vast majority of subjects were fitted with hearing aids from modality A (n=376), E (n=628) or F (n=96).

Modality	***A***	***B***	***C***	***D***	***E***	***F***
n	376	29	13	7	628	96
%	32.7%	2.5%	1.1%	0.6%	54.7%	8.4%
Mean COSI DC	4.03	4.03	4.27	4.24	4.25	4.24
Mean COSI FA	4.17	4.27	4.42	4.48	4.38	4.35
Mean AVAB DC	43.8%	52.8%	43.7%	49.7%	46.6%	38.3%
Mean AVAB FA	3.07	3.18	3.20	3.57	3.24	3.25

Table 1: Questionnaire data matched to hearing aid modalities (A-E), n indicates number of devices in each modality. COSI DC, COSI FA and AVAB FA are expressed in mean scores: COSI scores ranges between 1-5, AVAB FA scores ranges between 1-4. AVAB DC is expressed in a ratio of pre- and post-rehabilitation scores.

The results of linear mixed-effect model showed that differences between modalities were significant for the measures: COSI DC ($F(5,1125) = 5.38$, $p < 0.001$); COSI FA ($F(5,1122) = 5.22$, $p < 0.001$); and AVAB FA ($F(5,1143) = 9.73$, $p < 0.001$). Post-hoc analysis revealed that mean scores for COSI DC and FA were significantly higher for subjects that used modality E hearing aids relative to modality A ($p < 0.05$, Table 2). Furthermore, differences between AVAB FA and DC scores were also significant for modality A and F. Effect sizes of the differences between modalities varied between -0.28 and -0.42 (Table 2).

	COSI	AVAB
Degree of Change	E>A; -0.33	
Final Ability	E>A; -0.33 F>A; -0.28	E>A; -0.42 F>A; -0.40

Table 2: Post-hoc analysis results (Games Howell, α=0,05). Only significant differences between hearing aid modalities were shown, followed by the effect size (Cohen's *d*).

Dimensions of auditory disability

A linear mixed-effect model showed that interaction between the type of modality and the dimensions of auditory disability was significant for AVAB DC ($F(25,5715)$

= 1.71, p = 0.01) and AVAB FA ($F(25,5715) = 2.52$, $p < 0.001$). COSI DC and FA per dimension of auditory disability were not significantly dependent on the type of modality. The results from the post-hoc analysis are displayed in Table 3. Effect sizes for the significant post-hoc results were calculated to interpret the impact of the results. There was an overall trend that COSI and AVAB scores for modalities E and F were better than those of modality A. Though, one exception was found in the dimension SiQ, where AVAB DC scores were better for modality A as compared to modality F. Effect sizes of significant differences between modalities varied between -0.12 and -0.47.

AVAB	*Det*	*Dis*	*Loc*	*SiN*	*SiQ*	*Tol*
Degree of Change				**E>A**; -0.12	**A>F**; 0.43 **E>F**; 0.47	
Final Ability	**E>A**; -0.35 **F>A**; -0.44	**E>A**; 0.32	**E>A**; -0.45 **F>A**; -0.35	**E>A**; -0.43 **F>A**; -0.46	**E>A**; -0.20	

Table 3: Post-hoc (Games Howell, α = 0,05) analysis of mean AVAB DC and FA scores between the (most relevant) hearing aid modalities for each of the six dimensions of auditory disability, followed by the effect size (Cohen's d).

DISCUSSION

The focus of this study was to combine user experience of hearing aid rehabilitation with objective, technical hearing aid data, expressed in terms of hearing aid modalities. In this paper we present preliminary results, which address the relation between hearing aid modalities and user benefit. Modalities were defined using a data driven approach, which resulted in groups of hearing aids, independent of brand or type. Our results indicate that on a group level, significant differences exist between hearing aid modalities and individual rehabilitation goals evaluated with COSI. Similarly, this was also true for modalities and the dimensions of auditory disability evaluated with AVAB. Our study found that better COSI and AVAB scores could not be explained by an overall increase in feature potential. This is important information for the selection of hearing aids, as it suggests that more advanced hearing aids might not always solve auditory disability or be supportive for individual rehabilitation goals. The results imply that modalities can be considered a suitable and objective tool to support evidenced based hearing aid selection.

Feature potential expresses the mean number of channels, levels or type of a particular feature within a modality, rescaled between 0 and 1 (Figure 1). Accordingly, hearing aids related to modality B should be considered hearing aids with the highest feature potential. Yet, only in a few instances a hearing aid from this modality was used for rehabilitation. Nevertheless, modality A can also be considered as a modality with a high overall mean feature potential and was used in a large number of subjects. Interestingly, we found that over 95% of all hearing aids used for rehabilitation were related to either modality A, E, or F. Also, most subjects were fitted with a hearing aid with intermediate feature potential (modalities E and

F). The low number of used hearing aids that were related to modalities C and D, was perhaps less surprising. These two modalities represent hearing aids with a very limited mean feature potential. The selection of a specific hearing aid might be biased by the preference of the professional towards a certain brand or type. In the case of the dispenser, selection might also be driven by commercial interest. Further analysis of the existing data will provide a better understanding of the hearing aid selection process.

It is striking that the subjects in this study reported higher scores for hearing aids with an intermediate feature potential (modalities E and F), as compared to hearing aids that were related to a modality with a high overall feature potential (modality A). This clearly implies that the availability of a wider range of adjustable hearing aid feature channels or levels, does not necessarily result in more beneficial rehabilitation. This seems to be especially true for the number of compression channels, as differences for this feature were most pronounced between modality A and modalities E and F. Previously, Cox *et al.* (2014) reported a very small effect ($d = -0.06$) between hearing aids with 'premium' and 'basic' technology for older listeners (mean age 70.4 years) with mild to moderate sensorineural hearing loss, using several questionnaires. They considered that result to be non-significant. The terms 'premium' and 'basic' were also related to the number of available and/or adjustable hearing aid features and can thus be considered as a first-order approach of the modalities used in this study. In line with their findings, we also didn't find evidence that hearing aids with a higher feature potential (modalities A and B) were reported more beneficial as compared to hearing aids with a limited feature potential (modalities C and D).

Using objective measures (HASPI and HASQI) to evaluate hearing aid benefit, Kates *et al.* (2018) found some significant differences between manufactures, yet, they also found no significant differences between 'basic' and 'premium' hearing aids. They conclude that 'the similarity in performance between basic and premium devices suggest that increased processing complexity does not necessarily lead to improved performance'. Again, we conclude similar results. However, we compared a large number of commercially available hearing aids that were evaluated by a large group of users. This enabled us to extend comparisons beyond the dichotomy between 'premium' and 'basic' hearing aids. Furthermore, higher DC and FA scores were found for hearing aid types with a more intermediate feature potential as compared to hearing aids types with a high feature potential. This might be explained by the fact that this research included a vastly larger selection of different hearing aids. As a result, we were able to use a refined hearing aid classification method. Hence, differences between modalities are more detailed than just the dichotomy between 'basic' and 'premium'. The AVAB dimensions of auditory disabilities relate to distinct real-life hearing difficulties. The benefit of hearing aid features might therefore also differ between these dimensions. We found that AVAB DC results for the dimensions SiN and SiQ were dependent on the type of modality, but only for modalities A, E, and F. Interestingly, the only instance that subjects reported a significant higher benefit from a 'premium' type hearing aid, was in relation to the DC for the SiQ dimension. Differences in the level of AVAB scores for the ‘speech’ dimensions were significant, with mostly a medium effect size. This translates into important differences in perceived benefit. A possible explanation for this might be that problems related to these dimensions were prioritized during the hearing aid fit, regardless the selection of the hearing aid.

The AVAB FA results showed more significant differences between AVAB results per dimension and type of modality, except for the Tol dimension. The effects were most pronounced for differences between modalities A and E, and A and F. It could be argued that hearing aids with less complex directionality and less processing channels are more capable to handle problems related to auditory localization. In general, for most dimensions subjects reported the highest FA with a hearing aid that has an intermediate mean feature potential This indicates that hearing aids with the highest available and adjustable feature channels/levels are not always required for a good hearing aid fitting result.

Limitations and future

The existing data has a large potential for more elaborate analysis. For instance, it could be fruitful to examine differences between new and experienced users or between females and males, but also the relation to hearing loss and age. We hypothesize that there will be a clear effect of hearing aid experience on the perceived benefit in relation to modalities or relevant features. There might be a relation between hearing loss and/or age with respect to perceived benefit within different modalities. Furthermore, the data was not limited to the current six modalities and the data used to model the modalities could also be used for further analysis. In this respect, a regularization process can be considered to investigate which hearing aid features might be sensitive for the measures DC or FA. Such analyses would complement the present results and, as we expect, will lead to stronger predictions and more detailed conclusions. In a follow-up project the group results have to be translated to a more individual approach, feasible to support the clinical process of hearing aid selection and fitting.

The limitations of the COSI and AVAB questionnaires, as well as the added value of combing these two questionnaires, were previously discussed in Lansbergen *et al.* (2018). Especially, the ceiling effect observed in the COSI scores was found to be a limiting factor with respect to the overall sensitivity of this measure. This lack of sensitivity also translates to a poor analytic power when using the COSI with respect to the dimensions of auditory disability. On the other hand, main effects between mean COSI scores and the type of modality were clearly significant and in agreement with the results obtained with AVAB.

CONCLUSION

This study illustrated that more adjustable hearing aid feature channels/levels do not necessarily result in a larger perceived benefit. This implies that the ability to cope with real-life hearing problems is not solved by merely using more advanced hearing aids. Differences between perceived benefit of a hearing aid and available feature potential, encapsulated in modalities, were found to be specific for self-formulated rehabilitation goals and hearing problems associated with different dimensions of auditory disability. Although it is too early to fully understand what the underlying reasons for this outcome could be, our results are in line with results that were reported previously. Our results may be of interest for readers that work in the field of rehabilitation, and in particular for hearing aid dispensers and audiologists as it might help in hearing aid selection using an evidenced based method.

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