PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Assessing the interaction between different auditory profiles and benefit from six hearing aid processing strategies: Insights from the BEAR project

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ABSTRACT

The current study forms part of the Better hEAring Rehabilitation (BEAR) project, which aims to develop and evaluate new clinical tools for individual hearing loss characterization and hearing aid (HA) benefit assessment. The purpose of the current study was to assess the interaction between four different auditory profiles and two measures of hearing aid outcome obtained for six selected hearing aid processing strategies. Sixty older habitual hearing-aid users, who had previously been classified in four auditory profiles by a data-driven approach, participated in the study. All stimuli were generated with the help of a hearing aid simulator and presented via headphones. Speech recognition in noise was assessed at fixed signal-to-noise ratios based on individual 50%-correct speech reception thresholds measured in a realistic noise environment. Subjective ratings of overall quality and noise annoyance were measured using a multiple stimulus comparison paradigm. The four auditory profiles differed significantly in terms of the aided speech reception threshold (SRT) and interacted significantly with the HA processing strategies for speech recognition when target speech was presented at 90-degrees. Moreover, the correlations between the sentence recognition scores and subjective ratings differed among the auditory profiles.

Keywords: hearing-aid processing strategy, auditory profiles, hearing-aid evaluation

1. INTRODUCTION

Although modern hearing aids typically come with various advanced signal processing schemes, the treatment efficacy of these schemes in terms of hearing-aid (HA) fitting is still a matter of debate (1-4). A key issue is typically how much a given HA fitting can improve speech perception under adverse listening conditions (5). Even though the mechanisms governing speech understanding under adverse conditions are still not fully understood, it is important to investigate how benefit and preference from different hearing aid processing schemes varies from person to person.

HA fittings are typically evaluated using both objective and subjective outcome measures. Regarding objective measures, speech recognition in noise is the “gold standard”(5). A large number of studies have investigated how specific HA fitting parameters affect speech recognition performance, including directionality (e.g. (6, 7)), noise reduction (e.g. (8, 9)) and dynamic range compression (e.g. (10)). Subjective hearing aid outcome has also received much attention in the research literature, mostly using questionnaires (11, 12). Despite them enjoy a number of advantages such as reflecting real-life experience and having a well-established application in the clinic, there are disadvantages of using functional auditory assessments in evaluating HA outcomes. Especially for evaluating HA processing schemes, it is hard to verify and analyse how the processing of the acoustic input can affect the perception of the participants. For those reasons, other forms of subjective measures appear to be more suitable for HA evaluation. For instance, a multi-stimulus comparison test such as the well-known MUSHRA paradigm (MUlti Stimulus test with Hidden Reference and Anchor, (13)) is a time-

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efficient subjective measure applicable for evaluating hearing devices, which is also suitable for listeners with no technical experience (14-16).

It is well established that HA benefit can vary substantially across individuals. To achieve more individualized HA fittings, the BEAR project was recently initiated with the overall aim of developing new clinical tools for individual hearing loss characterization and hearing aid benefit assessment. Inspired by literature findings on supra-threshold hearing deficits, or “distortions”; e.g. (17-19), Sanchez-Lopez et al. (20-22) developed a test battery and a data-driven approach for classifying hearing-impaired listeners into four distinct auditory profiles. Under the assumption that these profiles benefit from different HA treatments, the current study hypothesized that the four auditory profiles would diverge in terms of their outcomes from different hearing aid processing strategies. To test this hypothesis, six HAs were evaluated using different objective technical outcome measures to represent different aspects of possible distortions in signal processing (23). In the present study, the selected HA settings were experimentally evaluated by a group of listeners previously divided into four groups based on their performance in an auditory test battery (22).

To achieve validity, hearing-aid outcome measures resulting from a perceptual evaluation should reflect real-life challenging noisy situations as much as possible (5). Older people with hearing loss particularly struggle with communication in noisy environments, for example a dinner table scenario with competing talkers and other distracting sounds (24, 25). Older listeners also find it difficult when the target speech is not coming from the front (26).

Our experimental design included listening scenarios in two spatial conditions with target speech presented from the front (0-degree) or from the side (90-degree) of the listener. Additionally, a speech-like distractor and realistic noise were included in stimuli. The hearing-aid outcomes were tested through a sentence recognition task and subjective ratings. In order to make hearing-aid outcomes comparable among participants, individual speech reception thresholds (SRT_{50}) were set as the baseline performance. We hypothesized that listeners from different auditory profiles would respond differently to 6 HA processing strategies in terms of sentence recognition scores and subjective ratings. Besides, it is expected that listeners from the four auditory profiles would also be likely to respond to the two spatial conditions differently for the same HA processing strategy.

2. METHODS

2.1 Participants

Sixty older participants (male = 30, female = 30) participated in the study. Their ages ranged from 60 to 80 yr (mean = 70.8 yr). Twenty-nine of them were recruited and tested at Odense University Hospital, Odense, while the other 31 were recruited and tested at Bispebjerg Hospital, Copenhagen. Four participants quitted the study after the first visit. Prior to this study, all participants completed a comprehensive auditory test battery (21). Based on these measurements, they were classified into four auditory profiles (22) : A (N = 14), B (N = 13), C (N = 20) and D (N = 8). The remaining five participants could not be clearly allocated to any of these profiles and were therefore excluded from all further analyses.

All participants had bilateral symmetrical sensorineural hearing loss and were habitual hearing-aid users (> 9 months of experience). The range of hearing loss configurations was chosen to lie in-between the N1 and N4 standard audiograms of Bisgaard et al. (27). The air-bone gap and interaural asymmetry in audiometric thresholds from 0.5-4 kHz were required to be maximally 15 dB. None of the participants had a history of any neurological or language disorders. All of them had self-reported normal or corrected-to-normal vision.

2.2 Test setup

The measurements were performed in either an anechoic chamber (Odense University Hospital, Odense) or a soundproof booth (Bispebjerg Hospital, Copenhagen). Audio playback was via an RME Fireface UC soundcard, an SPL Phonitor Mini amplifier and a pair of Sennheiser HDA200 headphones. All stimuli were generated with the help of a hearing-aid simulator (HASIM) implemented in Matlab (see Sect.2.5). A touch screen was used by the participants for the subjective ratings.

2.3 Test procedure

Each participant was asked to come for two visits and each visit took approximately two hours. At the beginning, SRT_{50} was measured to control the baseline performance level between participants.

For the SRT_{50} and sentence recognition measurements, the participants were asked to repeat the sentences that they heard. The responses were scored by an experimenter. Prior to the SRT_{50} measurements, there were two training trials. The thresholds were measured using a 1-down 1-up procedure with a step size of 4 dB for the first five presentations and 2 dB for the rest. The starting signal-to-noise ratio (SNR) was 6 dB. The SRT was the average of the presentations from the fifth and last sentence of the list. For the sentence recognition scores, there were 12 different measurements in total (6 HA x 2 spatial conditions), and the same measurements were repeated in the second visit.

Subjective ratings of overall quality and noise annoyance were collected separately between first and second visits. A multi-stimuli comparison method with hidden anchor (MUSHA) as implemented in the SenseLabOnline software from FORCE Technology was used. On each trial, participants were presented with a graphical user interface containing seven playback buttons and sliders (6 HA settings + 1 anchor stimulus) that allowed them to listen to the seven stimuli in any order and to rate them on a scale from 0-100, where 100 being the best. Each stimulus was rated four times per spatial condition.

2.4 Stimuli

The target speech stimuli were DANTALE-II sentences spoken by a female native Danish speaker (28). There were 16 lists, with ten sentences in each list. All sentences were grammatically correct and had the same syntactical structure. The target speech was presented from either at 0º or 90º from the front towards the ‘better’ ear. The better ear was defined as the one with the best unaided speech score as measured using the Danish Hearing In Noise Test (HINT) (29). The target was only played from 0º for the SRT_{50} measurement, while it was played from both 0º and 90º for the other measurements.

Two noise signals were used. Firstly, the International Speech Test Signal (ISTS; (30)) was used as a directional distractor from either 90º (when target speech in front) or 0º (when target speech from the side). To mimic a real-life situation, the second noise signal was a spatially diffuse cafeteria noise, which was recorded in a university canteen with a pair of hearing-aid satellites as previously done in (22). The distractor was 2 dB SNR respect to the diffuse cafeteria noise. The tested signal-to-noise ratio (‘test SNR’) for sentence recognition based on individual SRT_{50}, so that the performance level was relatively equal between participants. Due to technical limitations the SRT_{50} was rounded and the test SNR was fixed for the speech recognition conditions from a limited range of values. Therefore, the test SNR ranged from -6 to 12 dB SNR in steps of 2 dB. The SNR applied for the subjective ratings was test SNR + 4 dB for all six HA processing strategies and test SNR - 6 dB for the anchor. The anchor for the subjective rating was distorted by random binary masker to simulate the spectral distortion of the noise reduction scheme.

2.5 HASIM processing

The signal recorded from the frontal and rear microphones of a hearing aid was processed by a beamformer, a noise reduction algorithm and a wide-dynamic range compressor. The stimuli were linearly amplified according to the NAL fitting rule for the SRT_{50} measurements and the NAL-NL2 fitting rule for the remaining measures (31). Six HA processing strategies (see Table 1) were tested. Apart from HA6, which resembles conventional HA settings, and HA1, which stands for very basic processing, the other four HA contained aggressive processing features for different parameters to maximize their potential differences. The strong noise reduction refers to an attenuation of 15 dB while mild noise reduction applies 5 dB attenuation. HA6 corresponds to a hearing aid with similar parameters as a commercial HA. For further details of HASIM processing, see Sanchez-Lopez et al. (23).

Table 1 – Description of the six tested hearing aid processing strategies

	Directional processing	Noise reduction	Amplitude compression
HA1	Omnidirectional	Off	Slow
HA2	Omnidirectional	Strong	Fast
HA3	Binaural beamformer	Off	Slow
HA4	Binaural beamformer	Strong	Slow
HA5	Binaural beamformer	Strong	Fast
HA6	Cardioid	Mild	Slow

3. RESULTS

3.1 Data analysis

The median absolute deviation (MAD) method was used for identifying unreliable performances in sentence recognition. The test-retest differences in the scores were examined for this purpose. Difference scores exceeding ±2 MAD were considered unreliable (32). In these cases, the lower score of the two test-retest measurements was excluded. Otherwise, the average scores of the test-retest measurements were used and calculated into individual standardized scores. For the subjective ratings, we used the eGauge method (33) to exclude participants who were unreliable raters. This left us with 51 participants (A = 13, B = 11, C = 19, D = 8) for overall quality and 48 participants (A = 13, B = 12, C = 16, D = 7) for noise annoyance. Since each HA processing strategy was rated four times in each spatial condition, the median of the four ratings was used to calculate individual standardized scores.

For ANOVA and correlation analysis, the data was split based on the spatial condition for sentence recognition data. In the 90-degree condition, the measurements from HA4 and HA5 were excluded from the analyses because of a strong flooring effect (37.2% of the measures equal to 0). Statistical analyses for ANOVA were carried out using linear mixed effects (LME) models, implemented in R using the lmer function from the lme4 package (34, 35). The dependent variable was the individual standardized score. HA1 was set as the reference HA. The model also included the interaction between HA and test SNR as well as the interaction between spatial condition and test SNR to account for the influence from individual differences of SNR for the same HA. The random effect was the individual intercept. For subjective ratings, the dependent variable was also individual standardized score. The model was similar to the one in sentence recognition except there were more interaction (see Table 3). Correlation was tested through the Spearman method in R.

3.2 Influence of auditory profiles on test SNR

Figure 1 shows that the means of the test SNRs differed significantly between the four auditory profiles. The test SNR of profile C was significantly different from all other profiles and profile A had the lowest mean test SNR.

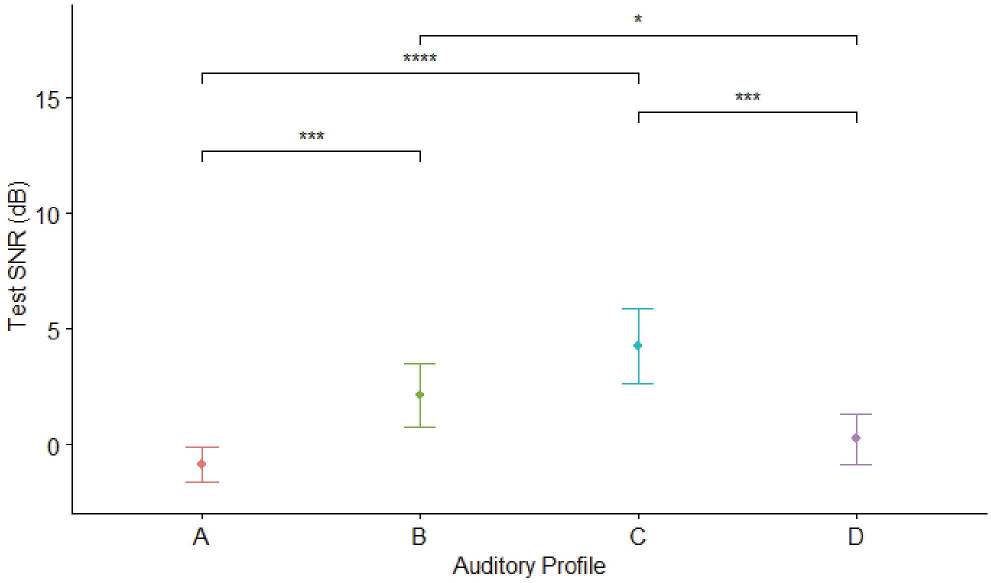

Figure 1: Means and 95% confidence intervals for the test SNRs of the four auditory profiles. Comparisons were run by t-tests. The bars above represent the pairs that had significant difference in terms of means. Notes for significant level: *: $p <= 0.05$; ***: $p <= 0.001$; ****: $p <= 0.0001$.

3.3 Influence of auditory profiles on HA outcomes

Table 2 shows the results from the ANOVA performed on the speech scores for each spatial condition. To simplify the analysis, the collected noise annoyance data were transformed so that better scores corresponded to lower noise annoyance. Significant effects of HA processing strategies and interactions with test SNR were shown in both outcomes. There was no significant effect of profile in either spatial condition for all three measures. The significant effect of the interaction between HA processing strategies and Profile on sentence recognition performance appeared in the 90-degree but not in the 0-degree condition (for details, see Table 2). There was no significant interaction between HA processing strategies and Profile on subjective ratings.

Table 2: Results from two ANOVAs performed on the sentence recognition scores.

		0 degree	90 degree
HA	df	5	3
	F	36.7	102.3
	p	**<0.001**	**< 0.001**
Auditory profile	df	3	3
	F	<0.1	0.4
	p	0.99	0.71
HA × auditory profile	df	15	9
	F	0.9	4.3
	p	0.55	**<0.001**
HA × test SNR	df	6	4
	F	0.8	6.4
	p	0.56	**<0.001**

Table 3: Results from the ANOVAs performed on the subjective ratings.

		Overall Quality	Noise Annoyance
HA	df	5	5
	F	41.8	15.6
	p	**< 0.001**	**<0.001**
	η2		
Spatial condition	df	1	1
	F	176.4	81.3
	p	**< 0.001**	**< 0.001**
Auditory profile	df	3	3
	F	0.4	0.3
	p	0.75	0.83
HA × spatial condition	df	5	5
	F	61.9	28.2
	p	**< 0.001**	**< 0.001**
Auditory profile × HA	df	15	15
	F	1.6	1.1
	p	0.08	0.30
Auditory profile × spatial condition	df	3	3
	F	2.9	1.3
	p	**0.03**	0.26
HA × test SNR	df	6	6
	F	8.5	3.9
	p	**<0.001**	**<0.001**
Spatial condition × test SNR	df	1	1
	F	3.5	4.2
	p	**0.03**	**0.04**
Auditory profile × HA × spatial condition	df	15	15
	F	0.9	1.4
	p	0.47	0.13

3.4 Correlations between speech scores and subjective ratings for each profile

In general, there were more significant (positive) correlations between the subjective ratings and speech scores in the 90-degree condition than in the 0-degree condition. Especially between the response of overall quality and sentence recognition scores, all profiles showed relatively large positive correlations (all $r \geq 0.4$, all $p < 0.01$) in the 90-degree condition while only one profile showed significant correlation in 0 degree (36). Profile B consistently showed typical or relatively large positive correlations between sentence recognition and the subjective ratings (all $r \geq 0.29$, all $p \leq 0.04$). Profile C showed significant correlations for most of the conditions while profile D only had significant correlations in the 90-degree condition. For profile A, this was generally not the case.

4. DISCUSSION

The results of our analyses of the interaction between HA processing strategies and auditory profiles were not as expected. Overall, there were no evident links between the four auditory profiles and outcomes from the six tested HA processing strategies. One possible reason is that we tested our participants based on individual SRT_{50} measurements. This could have 'evened out' the differences between the four profiles. As shown in Figure 1, the test SNRs differed significantly between the profiles. Setting SRT_{50} to begin with was mainly because we wanted all participants to have a relatively similar starting point in performance level. However, the individualized SNR of the stimuli, referred to test SNR in the previous section, can result in differences in terms of processing of the input signal within the same HA algorithm. For example, compression acts differently on different ranges of input level. Given that the mean test SNR of profile A was around 5 dB lower than profile C, the algorithms of the six HA probably worked differently between these two groups of participants. On the other hand, hearing aid users often encounter all sorts of SNR situations in their daily life, and it is not clear which of these affect a user's satisfaction the most. Another explanation could be that some of the tested HA were simply too 'aggressive' for all profiles, as indicated by the clear flooring effects in the 90-degree condition for sentence recognition in noise. Finally, despite using the same fitting formula for gain prescription, it could also be that people from different auditory profiles have greater benefits from different kinds of amplification (37).

The correlation analyses that we performed produced some interesting findings. Some profiles showed more positive correlations between sentence recognition scores and subjective ratings than others. The consistent positive correlations observable for profile B probably indicate that these users will be satisfied with their hearing-aid processing if speech clarity is guaranteed. For Profile A users, on the other hand, much less correlation between objective and subjective outcomes might imply that they are more demanding in terms of sound naturalness. As for profile C, it seems that noise annoyance is a more informative measure to predict their preference.

Moreover, the consistent correlations between overall quality and sentence recognition in the 90-degree condition also suggest that some relatively simple and quick subjective measures could be very informative. Clinical measures used during hearing aid fitting are mostly about verification (e.g. real-ear measures); little, if any, information is regularly collected about subjective preference for different processing schemes (38). For audiologists and hearing-aid dispensers, the choice of processing scheme is mostly based on personal experience or manufacturer's guideline (39). Given various individual differences for hearing-aid preference, a short and informative measurement for validation at the beginning is possible to improve the efficiency of the hearing aid fitting procedure.

5. CONCLUSIONS

The current study used two types of outcome measures for evaluating the interaction between four auditory profiles and six different hearing-aid processing schemes. The results indicated that the auditory profiles influenced HA outcome only in the 90-degree condition. This could have been a consequence of the experimental design that was used. Especially, individualized SNR of the stimuli according to their SRT_{50} might decrease the differences between auditory profiles to some extend. Since testing each listener at their SRT_{50} is not realistic, efforts should be made to provide an additional SNR benefit, by signal processing, to the profiles which showed elevated SRTs. The auditory profiles differed somewhat in terms of their correlations between the speech scores and subjective ratings, which may suggest that the speech understanding can drive their subjective perception in one group while others might be influenced by the comfort, listening effort or other aspects related to their hearing experience

ACKNOWLEDGEMENTS

This work was supported by Innovation Fund Denmark Grand Solutions 5164-00011B (Better hEAring Rehabilitation project), Oticon, GN Resound, Widex and other partners (Aalborg University,

University of Southern Denmark, the Technical University of Denmark, Force, Aalborg, Odense and Copenhagen University Hospitals). The funding and collaboration of all partners is sincerely acknowledged. The authors sincerely thank Rikke Skovhøj Sørensen (Technical University of Denmark) and Christer P. Volk (Force Technology) for their support. We also want to thank the participants and student helpers that took part in the study.

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