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PREDICTION OF INDIVIDUAL SPEECH INTELLIGIBILITY BENEFIT DUE TO NOISE REDUCTION IN HEARING AIDS

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ABSTRACT

Knowledge about how much speech-intelligibility improvement an individual hearing-aid user will achieve with specific settings is of great interest to fit a hearing aid optimally. While such knowledge exists for amplification, little is known so far about factors that determine speech-intelligibility benefit due to noise reduction (NR). This study aims to investigate to what extent real-ear measurements (REM), the audiogram, and spectro-temporal modulation detection ability predict NR-benefit. Experienced hearing-aid users were fitted with the same commercial high-end hearing aids using different recommended acoustical couplings, verified with REM. NR-benefit was quantified as the improvement in speech reception threshold (SRT) when changing from mild to strong NR in a spatial speech-in-noise setting. The Audible Contrast Threshold (ACT™) test was used as a modulation-detection measure to quantify supra-threshold hearing deficits. Closedness of acoustic coupling was assessed using real-ear occluded insertion gain (REOIG) measurements. The results show a high predictive value of REOIG for individual speech-intelligibility benefit due to NR, and the highest predictive accuracy for a linear combination of REOIG and ACT. The individual audiogram did not increase the predictive accuracy further and was a weaker predictor than the ACT-test.

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1. INTRODUCTION

Noise reduction (NR) algorithms can improve speech intelligibility [1-3] and can reduce listening effort [4] for hearing aid users. Most commercial hearing aids today consist of NR algorithms that exploit spatial and/or spectral cues from the acoustic scene. There is, however, a large variability of speech-intelligibility benefit due to spatial and spectral NR across patients [3,5], the origin of which is currently unclear, with some patients benefitting a lot and some not at all. Since NR algorithms may also introduce audible artifacts in the amplified hearing-aid output, there exists no individual prescription of NR strength based on patient-specific factors comparable to, for instance, that for prescribing hearing-aid amplification. Instead, a one-fits-all medium NR strength is often suggested, and the audiologist is left with finding optimal NR strength settings in time-extensive trial-and-error with the patient.

Investigations with early versions of NR algorithms [5] showed no correlation of NR-benefit with the audiogram. More recent findings [3] show, however, correlations between NR-benefit and performance in a spectro-temporal modulation detection (STMD) task. While more elaborate versions of NR algorithms and a clinically applicable test version [6] of STMD exist now, these relations, however, need to be revisited. Furthermore, an important factor to consider may be the closedness of the acoustic coupling, which has implications for the hearing aid fitting [7,8], because

more closed fittings allow more of the NR-processed and less of the unprocessed ambient sound to reach the ear drum of the patient [9].
The goal of this paper is to investigate the predictive value of three patient-specific factors and their combination on the speech-in-noise benefit that patients get from strong NR in hearing aids. The factors investigated are the audiogram, performance in a clinically applicable version of STMD testing, and the closedness of the individual acoustic coupling.

2. METHODS

2.1 Participants

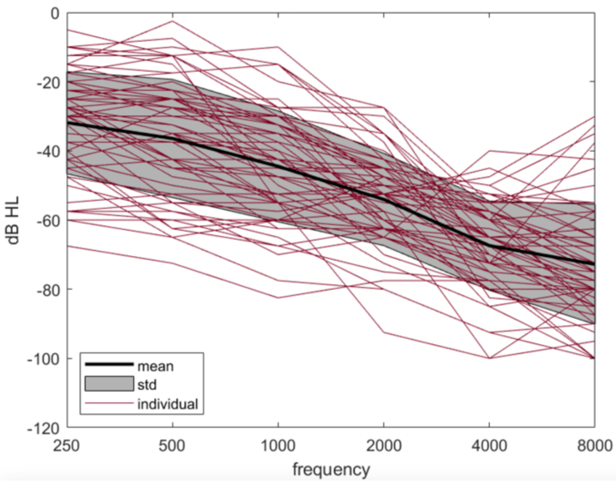

Figure 1. Audiometric thresholds of participants

27 experienced bilateral hearing-aid users (5 female) aged between 32 und 78 years participated in this study. Pure-tone thresholds assessed using standard audiometry are shown in Fig. 1. Air-conduction thresholds ranged from mild to severe. Subjects signed informed consent before the study conduction and were paid for participation. Ethical approval was granted by the Ethics committee of the University of Applied Sciences Lübeck.

2.2 Hearing aids and noise reduction schemes

Subjects were provided bilaterally with high-end hearing aids (Oticon More 1) that were fitted according to NAL-NL2, which was verified using REM. Acoustic coupling was chosen according to the manufacturer software's recommendation. Testing in the lab was started only after an accommodation period of at least 2 weeks.

2.3 Apparatus and calibration

Speech-in-noise testing was done in a living-room-like environment with the German Hearing-in-noise test (HINT) [10] in a three-loudspeaker design with frontal (0°) speech and noise from +100° and -100°. Two independent concurrent talkers reading audiobook material in German were used as noise in combination with stationary speech-shaped noise 6 dB below talker level. The adaptive procedure held the level of the frontal speaker constant at 65 dB SPL and varied adaptively the level of the two noise speakers to achieve 50% full sentences correct. Calibration was done using an NTI Audio XL2 level meter. Subjects were tested with HINT using two settings, mild NR and strong NR after passing two training runs, each with a new HINT list in randomized order without any NR active.
The Audible Contrast Threshold (ACT) test [6] was used as a clinically applicable version of STMD testing. Hereby, subjects listened via headphones to sequences of broadband noises that were intermittently mixed with a spectro-temporally modulated signal with 4 Hz temporal and 2 cycles/octave spectral modulation. The degree of modulation was adaptively varied to obtain the 70%-threshold point after a 3-out-of-5 Hughson Westlake criterion. Presentation was done binaurally ensuring at least 15 dB sensation level across the stimulus bandwidth [6]. After one familiarization run, the ACT test was performed twice (test and re-test).
To evaluate the closedness of acoustic coupling, real-ear occluded insertion gain (REOIG) was measured according to [7]. REOIG is defined as the difference between real-ear unaided gain and real-ear occluded gain and was measured here with an Interacoustics Affinity audiometer using real-ear tubes inserted to less than 3 mm from the eardrum of the subject.

2.4 Data analysis and statistics

For each participant, the four-frequency binaural pure-tone average (BPTA4) was extracted from air-conduction audiometric data, i.e., the average hearing loss across 0.5, 1, 2, and 4 kHz and across ears. A single ACT score was calculated as the average of test and re-test ACT score. To obtain one individual value of closedness of acoustic coupling per subject, REOIG values were weighted with the band-importance function for speech in noise from the Speech Intelligibility Index [11] and averaged for each ear separately. Afterwards, the most REOIG-negative, i.e., most closed of the two ears was taken as subject-specific value under the assumption that subjects will use the ear providing the better SNR for doing the speech-intelligibility test [12]. Pearson's correlation coefficients and linear mixed models were used in MATLAB and t-tests were conducted using Jamovi [13].

3. RESULTS

Fig. 2 shows SRTs with mild (red) and strong (green) NR settings both as individual data points (triangles) and box plots. In addition, the individual SRT-benefit, i.e., the difference in SRTs between strong and mild NR, is plotted as blue triangles overlayed with its box-plot representation. On average, listeners improved by -2.5 dB with strong NR, which is high statistically significant (paired samples t-test, $p < 0.001$). However, there were large inter-individual differences in SRT-benefit with many hearing-aid users benefitting more than 4 dB and some not at all.

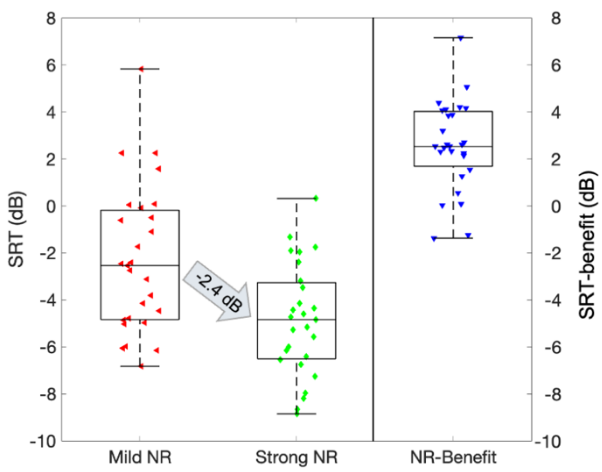

Figure 2. Speech reception thresholds (SRTs) and corresponding SRT-benefit due to NR.

Fig. 3 shows the correlation between closed-ear average REOIG and SRT-benefit due to NR. Each data point (circle) represents one hearing-aid user. Colors denote the type of acoustic coupling. Pearson's correlation coefficient revealed a highly significant negative correlation ($r = -0.5822$, $r^2 = 0.3390$, $p = 0.001$) indicating that subjects with a more closed acoustic coupling benefitted more than subjects with open fittings. The type of acoustic coupling itself was neither substantially indicative about the closedness of fitting, nor about the SRT-benefit due to NR. SRT-benefit was also significantly correlated to ACT ($r^2 = 0.2437$, $p = 0.008$) and BPTA4 ($r^2 = 0.2374$, $p = 0.01$) indicating that participants with higher thresholds benefitted more from NR. A linear regression model using REOIG and ACT as predictors delivered improved predictions of SRT-benefit due to NR ($r^2 = 0.447$, $p < 0.001$, root-mean-square error (RMSE) = 1.5 dB) compared to REOIG alone, whereas a model taking into account REOIG and BPTA4 delivered less improved predictions ($r^2 = 0.36$, $p = 0.005$, RMSE = 1.6 dB). Also, a combination of REOIG, ACT and BPTA4 ($r^2 = 0.447$, $p = 0.003$, RMSE = 1.5 dB) was not better than the model with combination of REOIG and ACT.

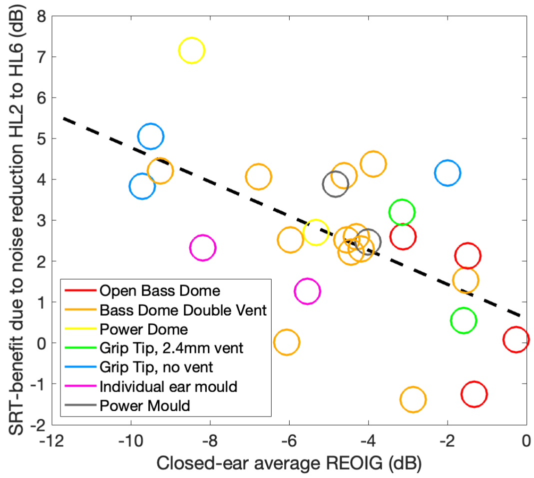

Figure 3. Correlation between SRT-benefit due to NR and closedness of acoustic coupling.

4. DISCUSSION

The closed-ear average REOIG was found to be the most important contributor out of the three investigated factors for predicting individual speech-in-noise benefit due to NR. The likely reason for this is that the closedness of the ear canal leads to a better blocking of ambient sound and therefore to a higher effectiveness of NR algorithms whose output is subject to less interference with the (noisy) ambient sound at the ear drum. While this concept has been studied in the literature based on average patient performance [8,9], the present study is the first to quantify the predictive value of the intra-individually well-reproducible variable REOIG [7] with respect to individual SRT-benefits in a challenging, but still realistic, sound environment.

In line with other studies (e.g., [5]) the contribution of the individual hearing loss was found to be of little importance for predicting the NR-benefit. This is reasonable since the participants were provided with optimal amplification for speech-in-noise performance irrespective of NR settings, which renders the absolute threshold values less important. In contrast, the higher predictive value of the ACT^{TM} test is in line with earlier work showing that performance in an STMD tasks delivers in itself good correlation with benefit from NR [3]. The correlation coefficient by using the ACT score alone in the present study is somewhat lower than that found by [3], which may be due to the fact that a novel generation of the NR algorithm within commercial hearing aids was used here compared to the relative aggressive NR setting used in [3]. Furthermore, the present paper used with the ACT test a novel clinically applicable version [6] of the STMD test in [3]. However, the high predictive value in combination with REOIG makes the ACT test an interesting candidate for characterizing supra-threshold patient performance and prescribing more individualized NR settings for hearing aids.

5. CONCLUSIONS

The closed-ear average REOIGs were found to deliver the highest predictive value of the individual speech-in-noise benefit that hearing-aid users achieve due to NR. The second-best predictor for NR-benefit was the score in the ACT^{TM} test. These two combined delivered the best linear model for individual NR-benefit, explaining 45% of its variance. The audiogram in form of BPTA4 did not deliver useful further information for improving predictions.

6. ACKNOWLEDGMENTS

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