Relating hearing aid users' preferred noise reduction setting to different measures of noise tolerance and distortion sensitivity

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Recently, there has been growing interest in the personalisation of hearing aid fittings. In two previous studies, we investigated preference for different types of noise reduction (NR) processing and found that we could partly explain individual differences based on audiometric and cognitive factors. In the current study, we explored a number of psychoacoustic and self-report measures in terms of their ability to help explain these results. Groups of hearing aid users with clear preferences for either weak ($N = 13$) or strong ($N = 14$) NR participated. Candidate measures included maximally acceptable background noise levels, detection thresholds for speech distortions caused by NR processing, and self-reported 'sound personality' traits. Participants also adjusted the strength of the binaural coherence-based NR algorithm to their preferred level. Analyses confirmed the basic group difference concerning preferred NR strength. Furthermore, detection thresholds for speech distortions were higher for 'NR lovers' than for 'NR haters'. In terms of maximally acceptable noise levels, there was a tendency for NR lovers to be less tolerant towards background noise than NR haters. Group differences were generally absent in the self-report data. Altogether, these results suggest that differences in preferred NR setting are partly related to individual sensitivity to background noise and speech distortions.

INTRODUCTION

Digital hearing aids (HAs) are typically equipped with a large range of signal processing algorithms such as noise reduction (NR) and directional processing (e.g., Dillon, 2012). Because individual users are known to respond very differently to such algorithms it is of interest to find ways for their individualisation. In two recent studies, we therefore investigated individual speech recognition with, and preference for, different types of NR (Neher, 2014; Neher *et al.*, 2015). In short, we observed

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large variability in outcome, which we could partly explain based on differences in pure-tone average hearing loss (PTA) and cognitive function. That is, we found participants with larger PTA and worse cognitive function to have weaker preferences for inactive NR and stronger preferences for strong NR than participants with smaller PTA and better cognitive function. These results could suggest that the former types of participants are more affected by noise and thus favour greater noise removal even at the cost of added speech distortions, whereas the latter do not.

The main purpose of the current study was to find out if the results summarised above are related to individual differences in noise tolerance and distortion sensitivity. In particular, it had the following three aims:

1. To confirm the previously observed differences in preferred NR setting using a method of self-adjustment;
2. To investigate if performance on two psychoacoustic measures of noise tolerance and distortion sensitivity can account for preferred NR setting;
3. To explore a novel 'sound personality' questionnaire in terms of its ability to reveal differences in preferred NR setting.

METHODS

Participants

For the current study, we recruited 27 participants aged 61-81 yr. All of them had taken part in our earlier studies and were experienced HA users with symmetrical sensorineural hearing impairments. Furthermore, all of them were screened for a number of sensory and neuropsychological deficits (cf. Neher, 2014). Eligibility for the current study was determined based on their overall preference for NR processing. Using the data from our previous studies, we computed an aggregate preference score per participant for 'inactive', 'moderate', and 'strong' NR (see below). From the 60 available participants, we then chose those 13 participants with the clearest preference for inactive NR ("NR haters") and those 14 participants with the clearest preference for strong NR ("NR lovers"). The two resultant groups did not differ in terms of age (73 vs. 70 yr, $p > 0.17$), PTA across 500 Hz to 4 kHz (45 vs. 47 dB HL, $p > 0.5$) or reading span (40 vs. 40% correctly recalled target words, $p > 0.9$; cf. Carroll *et al.*, 2015).

Test setup and HA signal processing

All measurements were carried out in a soundproof booth. They were controlled from a personal computer (PC) running the measurement software. This PC was connected to another PC via a digital audio interface. The other PC was running a real-time HA simulation (implemented on the Master Hearing Aid research platform; Grimm *et al.*, 2006), which was controlled via the measurement PC.

The HA processing closely resembled that we had used previously (cf. Neher, 2014). It included binaural coherence-based NR (Grimm *et al.*, 2009), NAL-RP amplification (Byrne *et al.*, 1991), and equalisation of the magnitude spectrum of the headphones used for stimulus presentation (Sennheiser HDA 200). Concerning the

NR processing, the algorithmic parameter that we varied was the processing strength indexed by the parameter α (cf. Grimm *et al*., 2009). Setting α to 0, 0.75, or 2 resulted in the inactive, moderate, and strong NR settings tested previously.

Speech stimuli

The stimuli closely resembled those we had used previously. They were based on recordings from the Oldenburg sentence test (Wagener *et al*., 1999; Wagener and Brand, 2005). To simulate a realistic complex listening situation we convolved these recordings with pairs of head-related impulse responses measured in a reverberant cafeteria using a head-and-torso simulator equipped with two behind-the-ear HA dummies (Kayser *et al*., 2009). Specifically, we used the measurements made with the front microphones of each HA dummy and a frontal source at a distance of 1 m from, and at the same height as, the head-and-torso simulator. For the interfering signal, we used a recording made in the same cafeteria with the same setup during a busy lunch hour. During the measurements, we presented this signal at a nominal sound pressure level of 65 dB and mixed it with the target sentences, the level of which we adjusted to produce a given signal-to-noise ratio (SNR).

Self-adjusted NR strength

To confirm the basic group difference concerning NR preference we asked our participants to adjust the strength of the NR algorithm such that they would be willing to listen to the stimuli for a prolonged time. Participants could make these adjustments in real-time using a slider on a graphical user interface displayed on a touch screen. Measurements were performed at two input SNRs: 0 and 4 dB. They started with two training runs (one per input SNR), followed by six test runs (three per input SNR) in randomised order. For the analyses, we used the median of the three self-adjusted NR strengths per input SNR and participant.

Acceptable noise level

To assess noise tolerance we performed measurements based on the acceptable noise level (ANL) test (Nabelek *et al*., 1991). Using a graphical user interface, participants had to adjust the level of the cafeteria noise three times in a row: (1) so they no longer could follow the target speaker, (2) so they could follow the target speaker very easily, and (3) so they would just about be able to tolerate the noise while trying to follow the target speaker for a prolonged time (the 'maximally acceptable noise level'). Unlike in the original ANL procedure, we presented the target speech at a fixed, nominal level of 65 dB SPL. We then obtained our ANL estimates by taking the difference between the nominal speech level and the maximally acceptable noise level. Note that, as in the original ANL procedure, a lower value therefore indicates more tolerance towards noise.

We measured ANLs for the inactive, moderate, and strong NR settings tested previously. The measurements with inactive NR served as estimates of general noise tolerance ('baseline ANL'). The measurements with moderate and strong NR served to verify the expected benefit from active NR with respect to (greater) noise tolerance. We started with six training runs (two per NR setting), followed by nine test runs (three per NR setting) in randomised order. For the analyses, we then used the median of the three ANL estimates per NR setting and participant.

Distortion sensitivity

To assess distortion sensitivity we used an adaptive 3-interval 2-alternative forced-choice paradigm coupled with a 1-up 3-down rule to estimate the 79.4% detection threshold (Levitt, 1971) for the distortions imposed onto the target speech (cf. Brons *et al*., 2014). The task of the participants was to choose which of two sound samples was different from a reference sound sample. The reference sound sample, which was always presented in the first interval, was an unprocessed speech signal. The target sound sample was the same speech signal processed with the NR gains computed for the speech-in-noise mixture. Before presentation, we equated the target and reference sound samples in terms of their root-mean-square levels. We then applied level roving of up to ±2 dB during the second and third intervals to prevent our participants from relying on any potentially remaining loudness differences, and also instructed them to concentrate on differences other than loudness to complete the task. There was one training run, followed by two test runs. Feedback was provided throughout. As our detection threshold estimate, we took the median of the last eight reversal points per test run and participant.

Self-reported sound personality

To assess self-reported traits related to noise tolerance and distortion sensitivity we used a new sound personality questionnaire intended to predict usage of, and preference for, different types of HA technology (Meis *et al*., 2015). This questionnaire consists of 46 items that were derived based on expert interviews as well as focus groups and in-depth interviews with normal-hearing and hearing-impaired listeners. In analysing the data from 622 predominantly older participants with different degrees of hearing loss, Meis *et al*. uncovered seven underlying factors: (F1) annoyance/distraction by background noise, (F2) importance of sound quality, (F3) noise sensitivity, (F4) avoidance of unpredictable sounds, (F5) openness towards loud/new sounds, (F6) preference for warm sounds, and (F7) detail in environmental sounds/music. In the current study, we explored the predictive power of these factors with respect to NR preference. For the analyses, we calculated the mean score across the items belonging to a given factor.

RESULTS

Self-adjusted NR strength

To analyse the self-adjusted NR strength data we performed a repeated-measures analysis of variance (ANOVA) with SNR as within-subject factor and listener group as between-subject factor. We found significant effects of SNR ($F_{1,25} = 12.5$, $p < 0.01$, $\eta_p^2 = 0.33$) and listener group ($F_{1,25} = 11.4$, $p < 0.01$, $\eta_p^2 = 0.31$) and a non-significant interaction of these two factors ($p > 0.5$). Consistent with our expectations, the NR haters preferred weaker NR processing than the NR lovers (mean α: 0.8 vs. 1.5; see Fig. 1). Also consistent with our expectations, both groups preferred stronger NR at 4 dB SNR than at 0 dB SNR (mean α: 1.3 vs. 0.9).

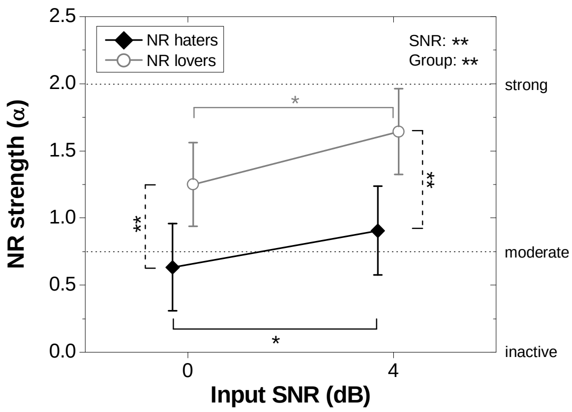

Fig. 1: Self-adjusted NR strength. Means and 95% confidence intervals for the two listener groups and input SNRs. α-values corresponding to inactive, moderate and strong NR are also indicated. * $p < 0.05$, ** $p < 0.01$.

Acceptable noise level

Despite several training runs, one participant was unable to perform the ANL test reliably and was thus excluded from the analyses. Performing a repeated-measures ANOVA with NR setting as within-subject factor and listener group as between-subject factor on the other data revealed a significant effect of NR setting ($F_{2,48} = 15.3$, $p < 0.00001$, $\eta_p^2 = 0.39$), a non-significant effect of listener group ($p > 0.7$), and a NR setting × listener group interaction that exceeded the 5% significance level slightly ($F_{2,48} = 3.0$, $p = 0.058$, $\eta_p^2 = 0.11$). For the NR lovers, noise tolerance increased by 3.7 and 4.5 dB with moderate and strong NR, respectively (see Fig. 2); for the NR haters, no statistically significant ANL changes were observed. This was due to the baseline ANLs (with inactive NR) of the NR lovers being about 2 dB higher (poorer) than those of the NR haters.

Distortion sensitivity

Since one (out of the 54) distortion sensitivity thresholds that we obtained was classified as an outlier we excluded it from the analyses. Performing a repeated-measures ANOVA on the remaining data with test run as within-subject factor and listener group as between-subject factor revealed a significant effect of listener group ($F_{1,23} = 5.7$, $p = 0.026$, $\eta_p^2 = 0.20$) and non-significant effects of test run ($p > 0.09$) and listener group × test run ($p > 0.8$). Consistent with our expectations, the NR lovers were less sensitive to the speech distortions than the NR haters (α-value at threshold: 0.44 vs. 0.31; see Fig. 3).

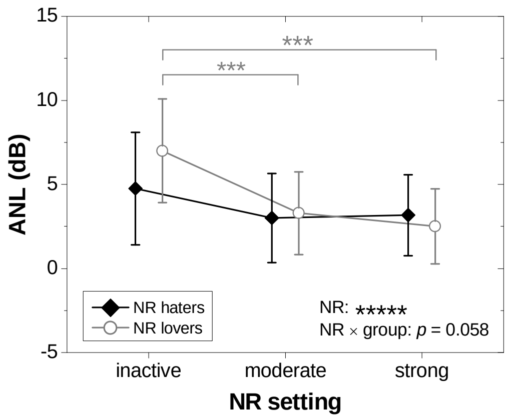

Fig. 2: ANL. Means and 95% confidence intervals for the two listener groups and three NR settings. *** $p < 0.001$, ***** $p < 0.00001$.

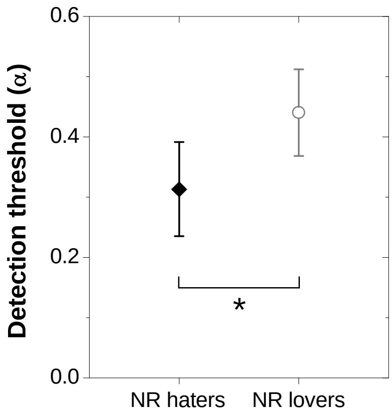

Fig. 3: Distortion sensitivity. Means and 95% confidence intervals for the two listener groups. * $p < 0.05$.

Self-reported sound personality

Figure 4 shows boxplots of the scores for the seven sound personality factors separated by listener group.

To check for any significant group differences we performed a series of two-tailed Mann-Whitney *U*-tests. However, none of these tests led to a significant result (all $p > 0.05$). Differences among the two groups were most apparent for F4 ('avoidance of unpredictable sounds'; $U = 1.8$, $p = 0.065$), followed by F6 ('preference for warm sounds'; $U = 1.3$, $p = 0.21$) and F3 ('noise sensitivity'; $U = 1.2$, $p = 0.24$).

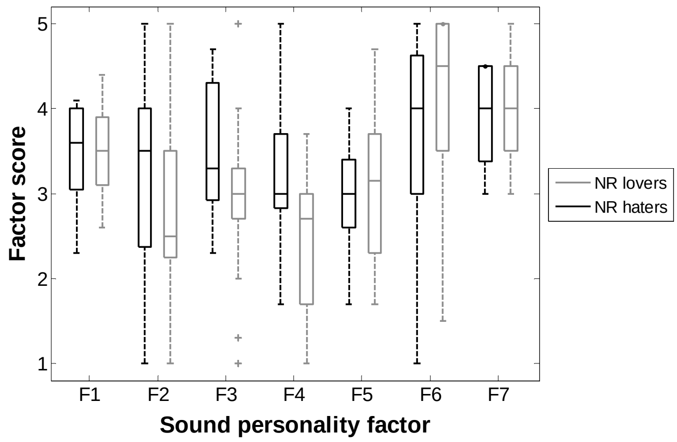

Fig. 4: Self-reported sound personality. Boxplots of scores for the seven factors.

SUMMARY

With respect to the three research aims outlined above, the results of the current study can be summarised as follows:

1. NR lovers set the strength of the algorithm tested here to almost twice the value chosen by NR haters, thereby confirming the group differences regarding preferred NR strength found previously with pre-selected (inactive, moderate, and strong) NR settings.
2. NR lovers obtained higher detection thresholds for speech distortions caused by the algorithm tested here than NR haters, indicating reduced sensitivity to such processing artefacts. Also, there was a (non-significant) tendency for NR lovers to have higher baseline ANLs than NR haters, indicating less tolerance towards background noise.
3. For the NR conditions considered here, the sound personality questionnaire did not reveal any clear differences among NR lovers and NR haters.

Altogether, these results provide a conceptual framework for factors seemingly involved in preference for NR processing (i.e., noise tolerance and distortion sensitivity). Future research should (i) confirm the putative link between preferred NR strength and baseline ANL, (ii) consider other types of NR algorithms, and (iii) apply the sound personality questionnaire to a wider range of HA conditions with a broader range of acoustical and perceptual effects.

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