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INFLUENCE OF CLINICAL FITTING RATIONALES ON ROLLOVER AT ABOVE-CONVERSATIONAL SPEECH LEVELS

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ABSTRACT

Hearing aids provide level-dependent gain to improve speech audibility. While more audibility typically leads to better speech intelligibility at low levels, several studies have found that at high levels increasing the presentation level can lead to decreased intelligibility. Termed rollover, this phenomenon has been observed in listeners with normal and elevated audiometric thresholds.

In two previous studies, we presented linearly and non-linearly amplified speech in quiet at above-conversational levels to hearing-impaired listeners via headphones and observed rollover in many cases. In the current study, we investigated rollover under more ecologically valid conditions. A group of adults with sensorineural hearing losses were tested with a wearable hearing-aid simulator that was fitted according to the NAL-RP and NAL-NL2 gain prescription rules. Speech intelligibility in background noise was assessed using a free-field setup.

We hypothesized that, at the group level, NAL-NL2 gains would lead to significantly less rollover than NAL-RP gains. To further our understanding of the mechanisms behind aided speech recognition at above-conversational levels, we compared our results to predictions based on the Speech Intelligibility Index.

Here, we present initial data from an ongoing study.

Keywords: *Speech recognition, aided hearing, gain prescription*

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1. INTRODUCTION

Hearing aids (HAs) provide non-linear amplification to improve the audibility of speech. While more audibility typically improves speech intelligibility (SI) at low levels, increasing the presentation level at high levels may lead to decreased intelligibility. Termed rollover (RO), this phenomenon has been observed in listeners with normal and elevated audiometric thresholds. To account for this effect, the Speech Intelligibility Index (SII; [1]) includes a so-called level-distortion factor that models performance decreases for speech levels higher than 72 dB SPL.

Recently, we investigated RO in 37 older, experienced HA users with moderate-to-severe hearing losses [2]. We measured word recognition scores in quiet and applied individual frequency-shaping in accordance with the 'National Acoustic Laboratories – Revised Profound' (NAL-RP; [3]) gain prescription rule to simulate aided listening. All stimuli were presented via headphones for better control of the experimental conditions. We found RO in 35 out of 74 test ears. Also, RO presence was associated with poorer speech-in-noise performance measured 10 dB above the individual most comfortable speech level, henceforth referred to as the 'MCL+10' level.

In a subsequent study, we measured SI in quiet with non-linear amplification [4]. A subset of the listeners from our previous study with clear RO was tested. The stimuli were amplified in accordance with the 'National Acoustic Laboratories – Non-Linear Version 1' (NAL-NL1; [3]) gain prescription rule and presented via headphones. At the group level, significant RO was observed, suggesting that at high input levels NAL-NL1 gains do not prevent RO.

Compared to NAL-NL1, 'National Acoustic Laboratories – Non-Linear Version 2' (NAL-NL2) gain prescription provides 3 dB less overall gain and higher compression

ratios at high input levels [5]. Therefore, NAL-NL2 may be better suited for preventing RO than NAL-NL1.
Since we previously had investigated RO in quiet with headphone-presented stimuli, the ecological validity of our results was limited. Because RO has also been observed under noisy conditions with non-linear amplification provided by real HAs [6], we chose to investigate RO in noise with a wearable HA simulator and the NAL-RP and NAL-NL2 gain prescription rules. Free-field presentation was used, to further improve the ecological validity. We expected that, at group level, NAL-NL2 gains would lead to less RO than NAL-RP gains. We compared our data to SII-based predictions to assess their ability to account for RO at the individual level.

2. METHODS

All participants signed an informed consent form and received a monetary reimbursement for their time.

2.1 Participants

Eleven adults with a mean age of 75.1 years (standard deviation, SD = 6.2 years) with mild-to-moderate, sloping, symmetrical, sensorineural hearing losses participated. They were recruited from the patient population of the hearing clinic at Odense University Hospital. Their mean pure-tone average hearing loss (PTA) across 500, 1000, 2000 and 4000 Hz was required to exceed 20 dB HL. The air-bone gap and interaural PTA difference was not allowed to exceed 10 dB. For each participant, the ear with the lower PTA was tested. For the 11 test ears, the mean PTA was 33.3 dB HL (SD = 4.3 dB HL). The top-left panel of Fig. 1 summarizes the audiometric data.

2.2 Physical test setup

All testing took place in a soundproof booth. Audiometry was performed using an Interacoustics Affinity 2.0 system with RadioEar DD450 headphones. All other measurements were performed with custom-made Matlab scripts executed on a Windows PC. Audio playback was via an RME Fireface UC soundcard, and a loudspeaker located in front of the participants at 1.4-m distance.

2.2.1 HA simulator

All HA processing was carried out with a wearable HA simulator [7] with a 10-band filterbank (0.1-10 kHz). Frequency-dependent gains prescribed for input levels from 0 to 110 dB SPL in 10-dB steps were stored in a table and linearly interpolated for intermediate levels. Two gain prescription rules were tested: NAL-RP and NAL-NL2. Only the NAL-NL2 gains varied with input level. Compression time constants of 5 ms (attack) and 60 ms (release) were used. Real-ear insertion gains were measured at 55-, 65- and 75-dB-SPL input level. All HA fittings were matched to target within ±5 dB between 0.5 and 4 kHz. Fig. 1 shows NAL-RP (top-right panel) and NAL-NL2 (bottom panels) target gains. Around 1-2 kHz, the NAL-NL2 target gains are clearly lower than the NAL-RP target gains.

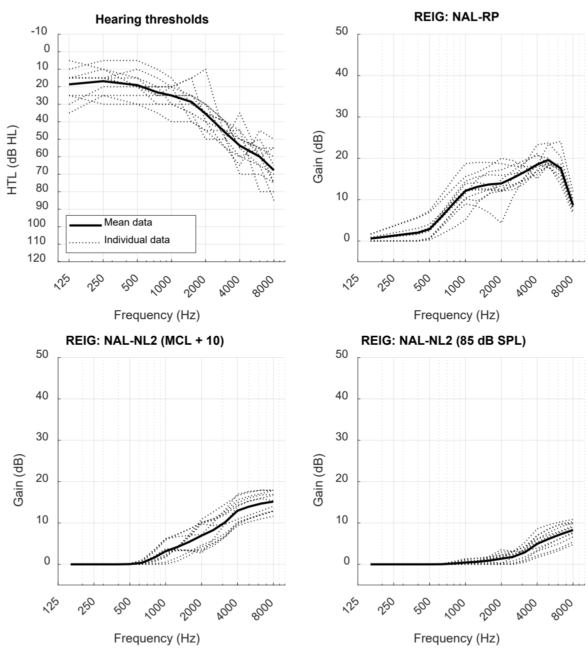

Figure 1. Top left: Mean and individual audiograms of the 11 test ears. Top right: Prescribed NAL-RP gains. Bottom left: Prescribed NAL-NL2 gains at MCL+10. Bottom right: Prescribed NAL-NL2 gains at 85 dB SPL. Dotted lines show individual data and thick lines average data.

2.3 Test procedures

All measurements were performed during two 2-hr sessions. The audiometry was carried out first. Next, MCL measurements were performed in quiet with running speech from the Dantale-I corpus [8]. The MCL was measured using NAL-RP amplification, as done previously [2]. The SI measurements were carried out afterwards.

2.3.1 SI measurements

For all SI measurements, test lists from the DAT corpus [9] were used. Each DAT list comprises 20 sentences with a fixed structure and two unique, unrelated keywords (e.g., “Dagmar tænkte på en teske og en næse i går” – “Dagmar thought about a teaspoon and a nose yesterday”).
The SI measurements were carried out with both gain prescription rules. Spectrally-matched (i.e., speech-shaped) background noise, provided by the DAT speech corpus, was presented during all measurements. For each gain rule and participant, a signal-to-noise ratio (SNR) that gave 50%-correct speech recognition was determined, with the speech level fixed at 65 dB SPL. The resulting noise level was used in all subsequent measurements. Two speech levels were tested, that is, MCL+10 (but not higher than 75 dB SPL) and 85 dB SPL in random order. In total, there were four test conditions (two presentation levels × two gain prescription rules). For each test condition, two DAT lists and thus 80 target words were presented. The proportion of correctly identified target words was calculated. This will be referred to as the speech recognition score (SRS).

2.4 Data analysis

A multiple linear regression analysis was performed. Since there were four datapoints (one per test condition) per participant, a mixed-effects model was used to account for within-subject effects. The built model comprised three predictors: gain rule, speech level, and gain rule × speech level. The two main effects were included as nominal variables (i.e., the exact presentation level in the lower-level condition was not considered). The MCL+10 speech level and NAL-NL2 gain rule were used as reference. Because of this, a non-significant effect of speech level would indicate a lack of RO in the NAL-NL2 data. The model assumptions (normally distributed residuals and variance inflation factor <5) were met.
To analyze the individual SRS data, SII predictions were computed. Individual speech levels, individual gains prescribed for these levels, as well as individual noise levels were used for this. Due to the small sample size and concerns about the data distributions, non-parametric Wilcoxon signed-rank tests and Spearman’s correlation coefficients were used for direct comparison of these variables.

3. RESULTS AND DISCUSSION

For the NAL-RP gain rule, the median test SNR was –0.54 dB (SD = 1.2 dB). For NAL-NL2, it was +0.66 dB (SD = 1.5 dB). The test SNRs obtained with NAL-RP were in all cases lower than those obtained with NAL-NL2. The difference between the two median test SNRs was significant ($V = 0$, $p < 0.001$). Consequently, the noise was presented at a lower level during the NAL-NL2 measurements than during the NAL-RP measurements (the speech was presented at the same level for the two rules).
The upper-left panel of Fig. 2 presents boxplots and individual SRSs obtained with NAL-RP as a function of presentation level. The median MCL+10 presentation level was 71 dB SPL (SD = 1.7 dB SPL). The median score obtained at MCL+10 was 60% (SD = 6%), while the median score obtained at 85 dB SPL was 46% (SD = 10%). The upper-right panel presents data obtained with NAL-NL2. The median score obtained at MCL+10 was 58% (SD = 7%), while the median score obtained at 85 dB SPL was 59% (SD = 10%).

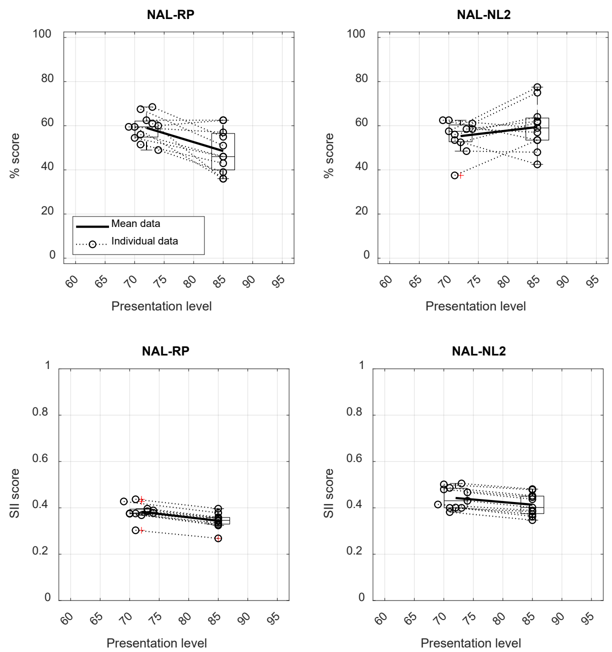

Figure 2. Top left: SRSs obtained with NAL-RP as a function of speech level. Top right: Corresponding SRSs obtained with NAL-NL2. Bottom left and right: Corresponding SII scores. Boxplots are shown with outliers marked by the red ‘+’ symbols. Circles

and dotted lines show individual data and thick lines average data.

The results from the linear mixed-effects model are summarized in Table 1. Only the interaction term was significant [$t(30) = -3.2$, $p = 0.003$]. Since the test condition corresponding to MCL+10 and NAL-NL2 was used as reference, these results suggest that the SRSs were comparable in all test conditions except for NAL-RP at 85 dB SPL. The negative sign of the interaction term implies that performance decreased at the higher level with NAL-RP gains. A Wilcoxon signed-rank test showed that the SRSs obtained with NAL-RP at 85 dB SPL were lower than those obtained at MCL+10 ($V = 53.5$, $p = 0.009$). These results suggest that, at MCL+10, the scores obtained with the two gain rules are comparable. At the higher level, the scores decreased with NAL-RP gains but not with NAL-NL2 gains. While this suggests that NAL-NL2 gains at 85-dB-SPL input are, on average, low enough to prevent RO, clear inter-individual differences are apparent (Fig. 2, upper-right panel). That is, some listeners show an increase in performance with level, whereas others show a decrease.

Table 1. Results from the mixed-effects model fitted to the participants' SRSs.

Model term	β	p
Intercept	55.0	<0.001
Gain rule	3.7	0.26
Speech level	4.1	0.21
Gain rule × Speech level	–14.6	0.003

The two bottom panels of Fig. 2 show the SII scores computed for each participant in the four test conditions. The median SII score obtained at MCL+10 was 0.38 (SD = 0.03) with NAL-RP and 0.43 (SD = 0.05) with NAL-NL2, with the difference in median SIIs being significant ($V = 1$, $p = 0.002$). This can be partly attributed to the higher test SNRs used for the NAL-NL2 measurements. The median SII scores obtained at 85 dB SPL were 0.35 (SD = 0.03) with NAL-RP and 0.40 (SD = 0.05) with NAL-NL2. In both panels, the SII scores consistently decrease with level, and for both gain rules the decreases are significant (both $p < 0.001$). While for NAL-RP, the SII decrease is consistent with the previously observed SRS decrease, this is not the case for NAL-NL2. Furthermore, in none of the four test conditions were the SRSs and SII scores correlated with each other (all $p > 0.25$). Overall, these results suggest that the SII is unable to predict individual performance at above-conversational speech levels.

3.1 Study limitations

The above results need to be taken with caution, due to two important limitations. First, as mentioned earlier, different test SNRs were used for the NAL-RP and NAL-NL2 measurements. If the same test SNRs were used, the SRSs obtained with NAL-RP at MCL+10 would likely be better than the corresponding scores obtained with NAL-NL2. Adding an additional test condition, where NAL-RP and NAL-NL2 are measurements are performed at the same SNR may help alleviate this limitation. The second limitation is the small sample size ($N = 11$). Further data collection is underway that is expected to allow for more in-depth analyses of individual performance differences.

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