

A New Hearing Aid Fitting Strategy for Severe to Profound Hearing Loss

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Abstract

A new fitting strategy for severe to profound hearing loss is proposed. This fitting strategy is based on the Cambridge Formula for multichannel compression [2]. The formula has been modified so that it takes into account that amplification may not support or even hamper hearing at certain frequencies. The new fitting strategy was evaluated by aided speech intelligibility tests. For 35 subjects, the new fitting strategy was compared with the subjects' own hearing aids through speech intelligibility tests. The same tests were performed with 20 ears of severe hearing-impaired test subjects outside of a clinical setting. For these ears, the new fitting strategy was compared with NAL-NL1 implemented on the same dynamic compression algorithm and with own hearing aids. The new fitting strategy performs well for the profound hearing impaired. For the severe hearing impaired, however, no improvement could be found. Some shortcomings of the new fitting strategy have been identified and improvements are suggested.

1 Introduction

In the 5-year research project "Audiologie-Initiative Niedersachsen", funded by the ministry of science of Lower Saxony, part of the research objective has been to predict post-surgical cochlear implant performance from pre-surgical data. Part of the pre-surgical test program were speech intelligibility tests where the patients were aided by a computer implemented software hearing aid. This paper concentrates on the prescription rule that was used to fit the dynamic compression algorithm to the individual hearing loss in these tests.

The dynamic compression algorithm was implemented in the "HörTech Master Hearing Aid" [1] (MHA). The MHA post-processed the sound data produced by an audiological workstation that performed the tests. Using high quality headphones, sufficiently high output levels could be achieved across all frequencies to ensure audibility in most patients.

The Cambridge formula for multi-band compression hearing aids [2] was adapted to meet the requirements of the severe to profound hearing impaired. In this paper we describe the new fitting strategy and report results of comparison measurements where the new fitting strategy was compared with own hearing aids and the NAL-NL1 [3] fitting rule.

2 Method

2.1 Fitting rule

The new fitting rule is based on the multi-band compression fitting rule described by B. Moore et al. [2]. This fitting rule was chosen because it provides balanced loudness for a wide range of levels. Compression was applied in nine overlapping frequency bands using a standard level meter with attack-and-release filter. Centre frequencies in Hz were 250, 500, 1k, 1,5k, 2k, 3k, 4k 6k, 8k for the different frequency bands. Attack times in ms were 20, 10, 5, 3, 2, 1, 1, 1, 1. Release time was 100 ms in all frequency bands. First tests with severe and profound hearing impaired subjects mandated modifications to the original fitting rule because of perceived and annoying distortions. These distortions were caused by the amplification of sound in all frequency bands, including frequency bands where the hearing threshold of the subjects was so high that any kind of amplification was unlikely to aid the subject's speech intelligibility. The resulting gains applied to the signal caused a maximum power output limiter to attenuate and clip the signal. This output limiter is required as a safety measure to prevent potentially harmful output levels. In order to prevent this kind of distortion, we modified the Cambridge rule so that the signal would only be amplified in selected frequency bands.

This idea of not amplifying sound in frequency bands where it was unlikely to help the subject has previously been proposed and used in the NAL-NL1 fitting rule [3]. For NAL-NL1, the authors inferred this decision from the speech intelligibility model used in the derivation of their prescription rule. For the severe to profound hearing losses targeted by the proposed prescription rule, it is likely that dead regions exist on the basilar membrane [5]. Amplifying frequencies inside dead regions is unlikely to help the subject's speech discrimination [4]. In selecting the frequency bands where gain would still be applied, a compromise had to be found between selecting the bands where the subject showed the lowest hearing loss, and the relevance of the respective frequency band to speech intelligibility.

The frequency bands to be excluded from amplification were determined by applying the following rules: all bands with hearing loss of 110 dB or worse are muted. If the minimum hearing loss across all frequencies is worse than 55 dB, 65 dB, 75 dB or 85 dB, respectively, all bands with a hearing loss above the exclusion threshold of 85 dB, 95 dB, 100 dB or 105 dB are excluded from amplification (i.e., muted). In a second step, the number of muted bands is increased further. This involves further reducing the exclusion threshold value (thus muting more bands) subject to the constraint that three of the four frequency bands in the speech-relevant range from 500 Hz to 2 kHz are not muted. If, however, the frequency of the minimum hearing loss is outside that range, the exclusion threshold value is reduced even further until two of the four frequency bands are muted.

The rationale for reducing the number of amplified frequency bands between 500 Hz and 2 kHz to only two or three was that often a steep increase of hearing loss is observed in this frequency region for the target hearing losses.

2.2 Experiments

The new fitting rule has mainly been used for pre-surgical speech intelligibility tests for cochlear implant patients. These tests did not compare the new fitting rule with other existing fitting rules. In order to compare the new fitting rule with other, pre-existing gain prescription rules, two comparison experiments were performed.

2.2.1 Experiment 1

The first experiment was performed by a subset of the cochlear implant candidates. 35 patients measured the Freiburger monosyllabic intelligibility tests in quiet at 65 dB SPL using two different aided conditions, their own hearing aids and the software-based MHA using the new fitting rule. The settings of the patient's own hearing aids were checked and optimized by clinical staff. The settings of the MHA were not modified after applying the proposed fitting rule, i.e. the first fit was used for measurements. In both aided conditions, the test was presented monaurally on the same ear.

2.2.2 Experiment 2

The second experiment was performed outside of a clinical setting with subjects paid on an hourly basis. Three different aided conditions are compared. Apart from the subjects' own hearing aids and the new fitting rule on the MHA, the subjects were also aided by the NAL-NL1 fitting rule on the same MHA configuration. On the MHA, the first fit was used, while the personal hearing aids were used unchanged.

In addition to the Freiburger monosyllabic test at 65 dB SPL, the Oldenburg Sentence Test in noise was performed with two different interfering noise types, static speech-shaped noise (olnoise) and fluctuating speech simulating noise (icra5-250) at a noise level of 65 dB SPL. For the Oldenburg sentence test, the speech reception threshold of 50% word intelligibility was measured by varying the speech level using an adaptive process [6].

3 Results

3.1 Results for Experiment 1

Figure 1 shows the histogram of the observed difference in individual speech intelligibility in quiet between the MHA with the proposed fitting rule and the subjects' own hearing aids for 35 cochlear implant candidates.

Data show that subjects usually have slightly better speech intelligibility when using the new fitting strategy. On average, subjects' speech intelligibility improved by 19 percentage points in the Freiburger Monosyllabic test, with a standard deviation of 21 percentage points. The presence of an improvement is significant on the 0.1% level.

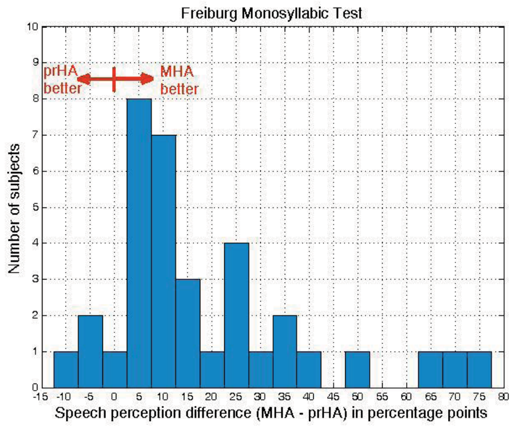

Figure 1: Differences in speech intelligibility using the new fitting rule with the Master Hearing Aid (MHA) software platform and the patients' own proprietary hearing aids (prHA).

3.2 Results for Experiment 2

For additional 20 ears with severe hearing loss, we compared speech intelligibility with the Oldenburg sentence test and the Freiburger monosyllabic test, using the new fitting rule and NAL-NL1, both implemented on the same MHA software hearing aid, and using the patients' own hearing aids. Average results from all three speech tests show the same ranking of prescriptions: The subjects performed best using their own hearing aids, slightly worse with the NAL NL1 fitting rule implemented on the MHA, and again slightly worse using the proposed prescription rule. The differences between the different aided conditions are however not significant.

With the Freiburger monosyllabic test at 65 dB SPL presentation level, subjects achieved on average 59±12% intelligibility using their own hearing aids, 48±12% intelligibility when using MHA with NAL-NL1 prescription, and 35±24% intelligibility when using MHA with the proposed fitting rule. Results for the Freiburger test are shown in Figure 2.

Using the Oldenburg sentence test with static speech-shaped noise, subjects achieved speech reception thresholds of -2.9±1.8 dB signal-to-noise ratio (SNR) when using their own hearing aids, -1.7±1.8 dB SNR when using the MHA with NAL-NL1 prescription, and -1.6±0.6 dB SNR when using the MHA with the proposed fitting rule.

For the Oldenburg sentence test with fluctuating, speech-simulating noise, subjects achieved speech reception thresholds of -3.8±3.1 dB (SNR) when using their own hearing aids, -2.8±3.3 dB SNR when using the MHA with NAL-NL1 prescription, and -1.4±1.6 dB SNR when using the MHA with the proposed fitting rule. Results for the Oldenburg test are displayed in Figure 3.

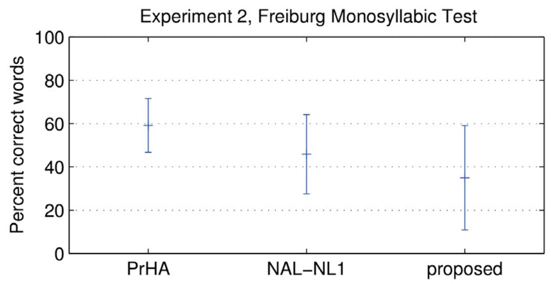

Figure 2: Speech intelligibility in quiet.

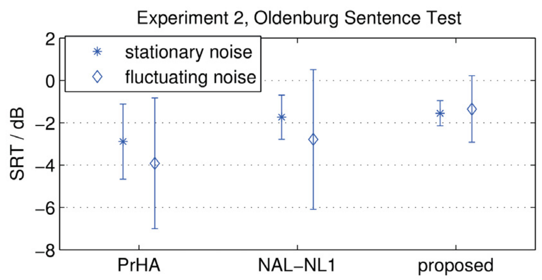

Figure 3: Speech reception threshold in noise.

4 Discussion

We have presented a modification of the Cambridge formula for fitting multi-band compression hearing aids that is also applicable for severe to profound hearing losses. Data show improved speech intelligibility compared to the subjects' own hearing aids when used in a clinical setup for cochlear implant candidates. The same improvement could not be reproduced with severe hearing-impaired subjects in a non-clinical setup.

The difference in results between the two experiments is most likely caused by the difference in the subjects' hearing loss. The tested clinical patients were candidates to receive a cochlear implant in the tested ear. Their hearing loss was higher than the tested non-clinical severe hearing-impaired subjects. The implemented method of reducing the number of frequency bands that perform amplification which worked well for the cochlear implant candidates was most likely too aggressive for these subjects and removed useful information from the output. Another possible explanation of the difference between experiments would be that the clinical group suffered from too low amplification in their own hearing aids. This however is not the case, as the settings of the hearing aids of the clinical group have been checked and optimized by clinical staff during the pre-surgical tests.

In the non-clinical experiment, the subjects' own hearing aids have not been checked or modified. Still, their hearing aids were fine-tuned by the hearing aid dispenser, while the prescriptions on the MHA were used without fine-tuning. This might also explain why the prescriptions on the MHA performed non-significantly worse in this experiment.

The proposed prescription shows improvements for cochlear implant candidates. In addition to the two experiments described in this paper, it has also been used for non-comparative speech intelligibility tests in additional 168 clinical patients. The large number of subjects measured allowed us to identify some shortcomings of the new fitting rule, which are addressed in an extended version of the fitting rule. This extended version may also improve performance of non-clinical subjects:

- Frequency bands excluded from amplification should not be muted, but the signal in these bands should be left unmodified. This might help with intelligibility some cases, and will not introduce distortions.
- For close-to-normal hearing threshold levels, which may also be present in cochlear implant candidates at some frequencies, the Cambridge formula may prescribe negative insertion gains. This was found to be detrimental to patients that had close to normal hearing thresholds at a few lower frequencies, but severe to profound thresholds across the rest of the spectrum. Therefore, negative gains will not be applied in the revised fitting rule.
- Frequency bands will we excluded from amplification less aggressively. A likelihood of the presence of dead regions will be computed from the audiogram [5] and will be used to determine if frequency bands need to be excluded from amplification. This will prevent the exclusion of frequency bands from amplification that could help speech discrimination.
- A transition to lower hearing losses was missing in the fitting rule, so that mild to moderate hearing losses could not be fitted with it. To help with this problem, the extended version now uses the unaltered Cambridge formula for all frequencies if the maximum hearing threshold level is not higher than 70 dB. This makes the proposed fitting rule generally applicable for all hearing losses.

The proposed changes to the fitting rule need to be evaluated in further experiments. Of particular interest is if the proposed changes can improve the performance for subjects with severe hearing losses, as well as for cochlear implant candidates that have some close-to-normal hearing thresholds at low frequencies.

Acknowledgement

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