Evaluation of interfaces for the self-fitting of personalized communication systems by hearing-impaired users

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Introduction

Due to the demographic change the amount of people with an age-related hearing impairment increases. While the majority of mild to moderate hearing losses is still unaided to various reasons, at the same time the usage of communication technologies and hence the need for unrestricted communication capabilities become increasingly important in modern life. To facilitate participation of hearing-impaired listeners in our communication society, the integration of well-known hearing support strategies into widely used consumer devices seems to be a promising concept. Whereas for medical hearing aids the fitting is traditionally guided by an expert, the present work aims at evaluating four "self-fitting" interfaces that should enable even less technophile users to adapt the large parameter set of nonlinear and complex hearing support algorithms to their individual sound preferences. The study was designed such that the same algorithm consisting of an 8-channel equalizer and a 3-band dynamic compressor was used for all interfaces. Its parameters, however, were tuned by the user in different ways. We investigate the duration of the fitting and the reliability and validity of its result.

Preset-based self-fitting

Three of the user interfaces (UIs) provide a selection of the preferred sound setting among a set of parameter presets. These have been derived from different degrees of age-related hearing losses according to ISO 7029 [1] to which the fitting rule NAL-R [2] was applied. Throughout the fitting presets are varied and applied to always the same audio signal whose sound is to be adjusted.

2DTouch: This UI enables the user to adjust the sound setting by moving a cursor within a two dimensional coordinate system on a touch screen. Labelled as "timbre", the abscissa controls the presets' indices arranged with ascending high frequency gain. The ordinate enables the variation of "loudness" by technically referring to the overall gain (dB) at the input of the hearing support stage.

Knobs: Two haptic rotary knobs provide control of the same two dimensions described above. A computer screen displays feedback about the knob's rotation angle within the relevant range.

Adaptive paired comparisons (APC): The overall preferred preset is tracked by means of a series of pairwise comparisons. In each iteration, the user is asked to choose among two sound settings, denoted by "A" and "B". Starting with two clearly audible different presets an adaptive heuristic selects the presets for the next iteration from the index space in the direction of the previously preferred alternative. Throughout the procedure the step size and distance between presets are reduced, resulting in more and more similar presets until the overall preferred preset is found or no difference can be detected anymore. In addition, "loudness" can be manually adjusted via a peripheral slider.

Categorial loudness production (CLP)

In this approach three third-octave band noises centered at 500, 2000 and 6000 Hz are presented to the user, who is requested to adjust their levels via button control until they match each of the four loudness categories "just audible", "soft", "medium" and "loud". This results in an individual loudness function, which is fitted to the four data points and then compared to the average loudness function of a normal-hearing sample [3]. The difference between the loudness functions along the abscissa corresponds to the gain which is provided by the hearing support algorithm.

Experimental method

Our experiment was divided into three sessions. The first two comprised the self-fitting runs for each of the four UIs. Session 2 thereby was a retest repetition of session 1. In session 3 the validity of the fitting results was assessed.

Part A: Self-fitting

15 subjects (7 female) with mild to moderate sensorineural and sloping hearing loss of 80 dB HL at most and aged between 59 and 78 years participated in the listening tests. Slight asymmetries between ears were allowed such that the maximum difference between the pure tone averages (PTA) of both ears was about 7.5 dB. Eight subjects regularly wear hearing aids in their daily life. During the fitting, test signals were presented via a Sennheiser HDA 200 headphone which had been equalized to produce a flat response at the coupler. For the preset-based UIs the fitting was repeated for 8 different test signals (speech recordings from the scenarios telephone, radio and television including typical degradations as well as background noise and music in case of the latter two scenarios). The order of UIs and signals were randomized. Both the overall duration and the resulting set of hearing support parameters were recorded.

Part B: Validation of sound setting

All but one subjects took part in the third session in order to validate the sound settings produced in the self-fitting runs. For this purpose a subset of 4 speech signals was selected from the 8 test signals that had been involved in the preset-based fittings. To each signal the hearing support algorithm was applied given the parameter sets from the four UIs (we selected those of session 1). The differently processed versions of the signal were then presented in pairs. For each pair the subject was asked to state which sound setting was preferred. For reference, stimuli processed according to a standard fitting rule NAL-NL2 [4] and the original unprocessed signals were included, resulting in 6 conditions to be compared (in 15 pairs) for each test signal. Both the order of signals and comparisons were randomized.

Results

Part A: Self-fitting

The mean fitting duration (see Fig. 1) was below one minute for the UIs 2DTouch and Knobs, and about two to three times as much for APC. For all preset-based approaches a significant reduction of duration with increasing position in the order of measurements was observed indicating a strong impact of the user's familiarization to the interface. CLP required about 4 minutes for unexperienced users. Since only one run per session was performed, no valid statement about a possible speed-up of CLP due to further training can be made.

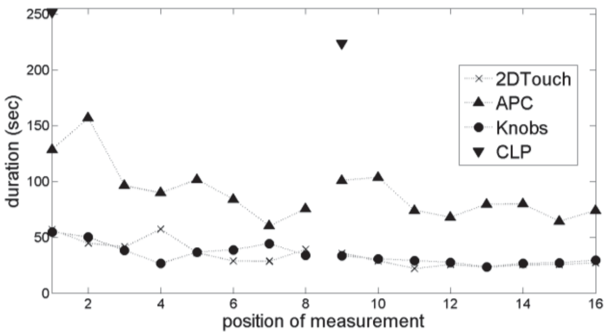

Figure 1: Temporal course of the mean self-fitting duration. The 9th point marks the start of the second session. For CLP only one fitting run was performed in each session.

To assess test-retest reliability, the similarity between the modifications produced by the hearing support algorithm when applied to a speech signal employing the fits from the first two sessions, was expressed by means of linear correlations. To this end the degree of modification imposed to both the speech signal's spectrum and its dynamic range were estimated. The former was represented by the long term third-octave levels, and the latter by the difference between the 99% and the 30% percentiles of short-term levels calculated within the same bands [5]. A Euclidean metric was then applied yielding distances between the original and the processed signal. This analysis was carried out for all 8 test signals (which were also considered for CLP) and the fits from both sessions. Finally, the distances were correlated between both sessions. Figure 2 shows the correlation plots for the Knobs UI. Table 1 summarizes the correlation coefficients for all UIs. Correlations are very strong in case of the dynamic range reduction and somewhat weaker, but still strong in case of spectral modifications.

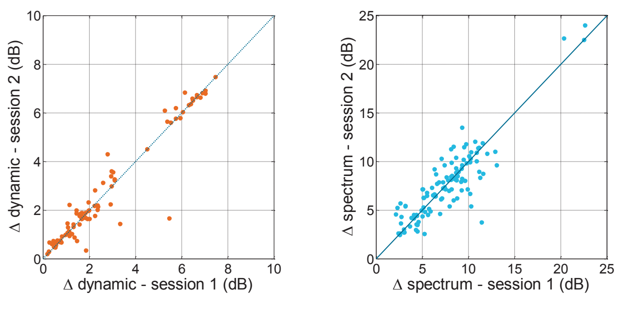

Figure 2: Correlation of dynamic (left) and spectrum (right) distances between test and retest session (see text) for the Knobs UI; each data point relates to a different test signal and subject.

Table 1: Pearson's linear correlation coefficients between test and retest for dynamic and spectrum modification (see text).

	2DTouch	*Knobs*	*APC*	*CLP*
dynamic	0.951	0.994	0.992	0.993
spectrum	0.736	0.884	0.669	0.709

Part B: Validation of sound setting

The preference rates derived from the paired comparisons are 20.83 % for APC, 18.69 % for Knobs, 18.21 % for 2DTouch, 17.62 % for the unprocessed signal, 13.21 % for CLP and 11.42 % for NAL-NL2. These values indicate that the preset-based fits might have been slightly preferred to the unprocessed signal. In contrast, NAL-NL2 and CLP performed worse than the original. One must note, however, that in our experiment the spontaneous acceptance was assessed, which is known to be poor for audiological fitting rules that usually require some period of acclimatization.

Conclusion

All four UIs provide a fast and reliable adjustment of hearing support parameters. Without acclimatization preset-based fits seem to be preferred to those produced by CLP and NAL-NL2 and at least not rated worse than the unprocessed signal. Further studies will have to explore the benefit that can be achieved in terms of sound and speech quality perception into more depth, focus on usability aspects and investigate performance in specific applications.

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