Profiling hearing-aid sound

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Assessment of audio quality has a strong tradition within concert hall acoustics, music reproduction and telecommunication, and some of the associated methods have recently been applied to hearing aid sound (Simonsen and Legarth, 2010). Many assessment methods have been developed and evaluated, and one of the most valuable methods is the use of assessment panels consisting of trained listeners (e.g., Legarth *et al.*, 2012). Considerations about sound quality are an integral part of hearing-aid development as hearing-aid gain strategies and processing modify the sound by applying, e.g., frequency-dependent gain and dynamic-range compression, in order to compensate for consequences of hearing impairment. Hearing-aid manufacturers use different processing principles and different signal-processing technology to obtain this compensation. In the present study, the aim was to obtain the sound-attribute profile for Widex devices and compare this to profiles of devices from other manufacturers, as well as an earlier Widex device. The listening panel comprised listeners with hearing impairment and was provided by DELTA SenseLab. The sound preference of the listening panel was also measured in a variety of acoustic scenarios focusing on speech and music conditions. It was found that the sound profiles of the different manufacturer devices were different and that this may be explained by differences in processing principles and technology.

INTRODUCTION

The aim of the signal processing in modern hearing aids is to provide the optimal gain and feature strategy to allow the hearing impaired to hear similarly to normal hearing listeners without compromising sound quality with regards to comfort and naturalness. Different manufacturers apply different principles and technology to reach these goals. Effectively, this means that the overall perceived sound quality of devices from different manufacturers can be quite different. The present study aims at quantifying subjectively perceived sound quality using a number of sound attributes, and identifying a manufacturer-specific *sound signature*. It is hypothesized that sound quality profiles are different across hearing-aid manufacturers and may also be similar across series within one manufacturer.

Sound quality assessment has been used for general product sound evaluation in many applications. The methods and analysis tools originate from a broader field of sensory evaluation, which have proved to be very influential in, e.g., the food industry. It is common to use a panel of trained assessors, who have a common

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Proceedings of ISAAR 2013: Auditory Plasticity – Listening with the Brain. 4th symposium on Auditory and Audiological Research. August 2013, Nyborg, Denmark. Edited by T. Dau, S. Santurette, J. C. Dalsgaard, L. Tranebjærg, T. Andersen, and T. Poulsen. ISBN: 978-87-990013-4-7. The Danavox Jubilee Foundation, 2014.

language and proven sensitivity to small quality differences. Sound reproduction systems for listening to music and entertainment have historically also had very fruitful use of quality assessment. In assessment methods the goal is often to establish a set of meaningful sound quality attributes and explore how these are related to preference or perceived ‘good’ quality (e.g., Gabrielsson and Sjögren, 1979). Sound quality assessment in the hearing-aid industry deviates from other consumer industries since listeners with hearing impairment may perceive sound quality differently from listeners with normal hearing. It is, however, unclear whether a group of listeners that are uniform with regards to pure-tone audiometry will have similar sound quality perception. In the present study, a perceptual sound quality evaluation was conducted, using a panel with trained listeners with homogeneous sensorineural hearing impairment.

METHODS

Assessor panel

The panel of listeners was developed by DELTA SenseLab. Their panel consists of a number of listeners with moderate sloping hearing loss (N3) (Legarth *et al.*, 2012). An assessor can only be included in the panel based on a satisfying evaluation of his ability to reproduce data in identical conditions and show sensitivity to changes in sound quality. Eleven listeners participated in this study. The execution of the experiment and the administration of the listeners were handled by DELTA SenseLab, who were paid for their services.

Attributes and acoustic scenarios

In order to show various aspects of sound quality, a number of sound samples were used for different test scenarios, comprising babble, female speech, male speech, pop music, classical music, traffic and nature. Overall aspects of preference and attributes were evaluated by the listening panel for all these scenarios. In the first part of the assessment, the panel was asked to rate sound samples according to preference, while in the second part, more detailed information about the perceived sound quality was obtained. The panel evaluated the sound samples according to six attributes of sound quality, namely ‘naturalness’, ‘fullness’, ‘loudness’, ‘sharpness’, ‘distortion’, and ‘tube sound’. These six attributes were chosen on the basis of earlier experiences of DELTA SenseLab.

Devices

The present article presents the results obtained with the assessor panel for four hearing-aid devices: (A) a current Widex device, (B) a Widex device from year 2005, (C) a current competitor device #1 and (B) a current competitor device #2. All devices were set up with proprietary fitting rationale recommended by the manufacturer. In conditions of music signals, a recommended music/entertainment program was chosen.

Recording setup

The stimuli that were presented to the subjects were recorded at Widex facilities according to guidelines of DELTA. Recordings were made with devices mounted on the KEMAR and sound was played back using a 5.1 loudspeaker setup, using multichannel sound files provided by DELTA SenseLab. Closed BTE moulds, with 1.5-mm venting recommended for the given hearing loss, and standard hearing-aid tubing were used. The premise was that the devices should be exposed to the same stimuli presented in the same setup. The aided sound was recorded by use of the coupler microphone. The resulting sound files were then sent to DELTA and scrambled, such that the recorded devices were blinded to their test leaders and assessors.

RESULTS

Preference

In this section, the rating of preference is presented, in terms of ‘overall device preference’, ‘device preference for male speech in quiet’ and ‘device preference for classical music’. The data are presented as the mean device ratings across listeners on a 100-point scale, and the error bars reflect 95% confidence intervals. Figure 1 shows the preference ratings overall and for the two specific conditions.

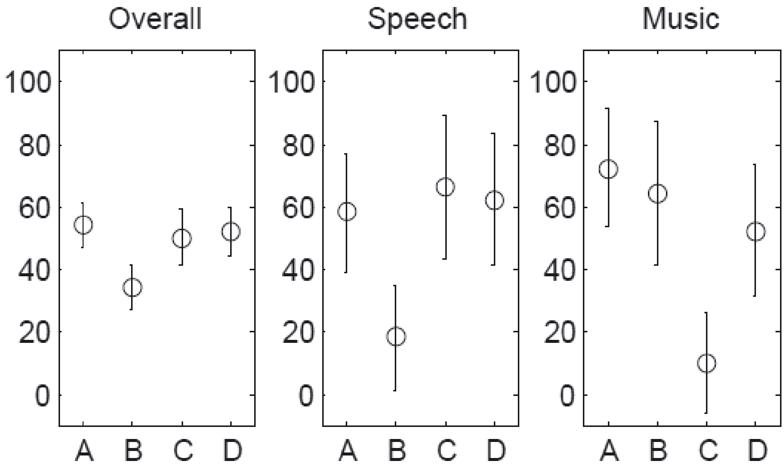

Fig. 1: Preference ratings for ‘overall’, ‘speech in quiet’ and ‘classical music’.

In overall preference, devices A, C, and D are not significantly different, while device B is rated significantly poorer than the three others. From the middle panel it can be seen that devices A, C, and D achieve similar ratings for male speech, while device B is rated significantly lower with regards to preference. The confidence intervals are larger due to the lower number of responses that the mean data are based on. The right panel shows the data from the condition where classical music was the stimulus. Here the pattern is different, as devices A and B are rated higher than C and D, while the devices A, B, and D are rated significantly higher than C.

Profiles

Many factors of subjective perception are involved in the determination of preference. So in order to obtain a higher resolution of the preference rating, six sound quality attributes were tested. Figure 2 shows the ratings of 'naturalness' of the four devices, averaged across scenarios. This is shown as an example, and similar data were obtained for each of the six test attributes. There is a trend in that device A has the most natural sound. Device A also had the highest overall preference rating. Interestingly, device B had a relatively low rating on overall preference, yet reaching a rather good rating on naturalness. This illustrates that preference does include and combine elements from a set of sound quality attributes.

To show the subjective rating from all six attributes at once, Fig. 3 shows 'spiderweb plots' where each point in the hexagon indicates the rated value of each attribute. By connecting the data points in this graphical representation, the sound profile of a test device may be visualized, and thereby compared for the four devices.

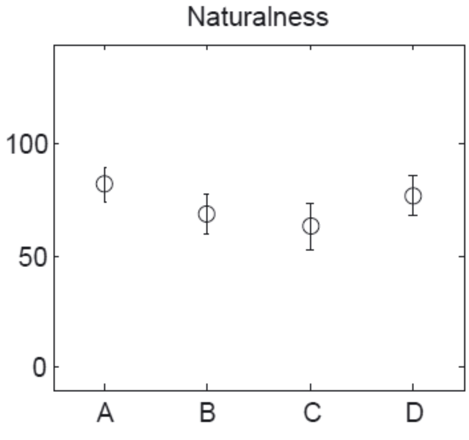

Fig. 2: Results for the average rating of 'naturalness'.

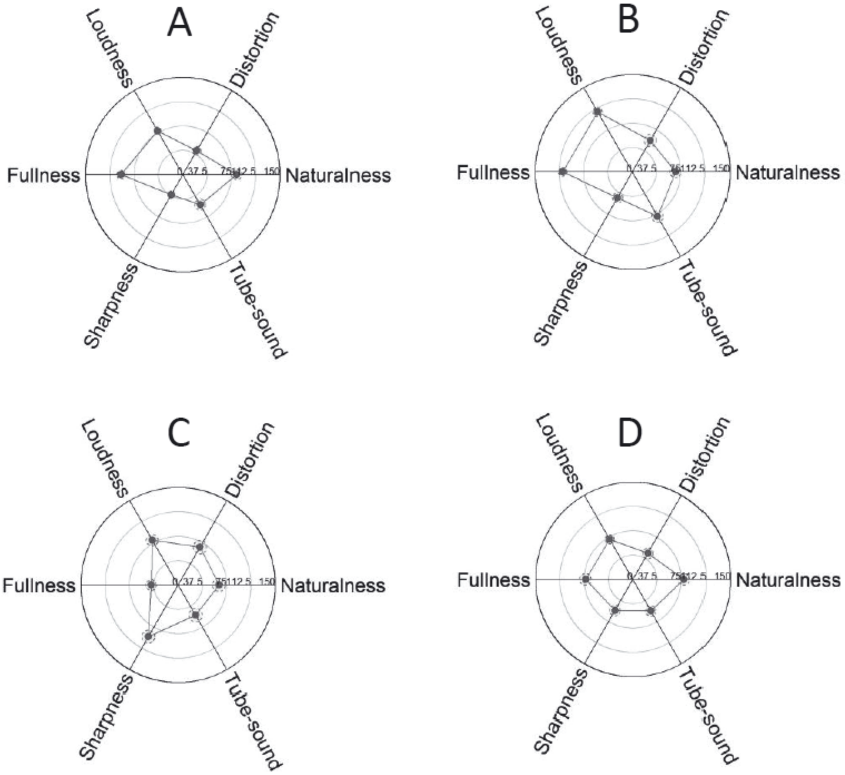

Fig. 3: Sound-attribute profiles of the four test devices. The radius of the symbol represents 95% level of confidence.

The timbre characteristics represented by ‘fullness’ and ‘sharpness’ show differences in the products. Device D shows a medium level of fullness and sharpness, whereas device C has much treble and little bass, leading to a sharp sound. Devices A and B are both rated high on fullness which indicates a sound with a strong bass reproduction. The individual product characteristics can be described from the profile plots (Fig. 3):

A. Very full (bassy) sound with little ‘sharpness’ and low level of ‘distortion’.
B. The most bassy (high on fullness) device, and also significantly louder than any other devices. It has a high rating on ‘tube sound’ which could be related to by the high loudness rating.
C. A sharp/thin sound with some ‘distortion’. Lowest rating on ‘naturalness’.
D. Medium fullness and sharpness. Average ‘loudness’, ‘distortion’, and ‘tube sound’.

Looking at the shapes of the profiles, it appears that devices A and B have a similar tilted rectangular shape, even though device B has higher values in ‘loudness’, ‘fullness’, and ‘tube sound’. These tilted rectangles are somewhat different from the shapes of devices C and D. This is interesting, as these devices are from the same manufacturer, namely Widex. This would suggest that the shape identifies the Widex sound signature, since they are both Widex devices. Devices C and D come from other manufacturers and clearly have different sound profiles.

DISCUSSION AND CONCLUSIONS

It was possible to identify a Widex sound signature based on the panel’s evaluation. Whether this sound profile is optimal and most preferable is not given as such. However, for particular attributes there is an intuitive link between good sound quality and preference. An attribute like ‘naturalness’ seems like something that should be as high as possible to be preferred, while ‘distortion’ and ‘tube sound’ can be associated with poor sound quality and should be minimized. The remaining three attributes, ‘loudness’, ‘sharpness’, and ‘fullness’, do not have clear relation to poor or good sound. With the present data, it is not possible to conclude anything about a clear relation between the tested attributes and preference. However, if more data were available, it could be possible to create a map from attribute rating to preference, using methods of factor analysis or principal components.

The hearing-aid sound is thought to be strongly associated with the manufacturers’ fitting rationales and underlying audiological principles. It is assumed that the manufacturer responsible for device C provides a fitting rationale with more high-frequency gain compared to devices A, B, and D, leading to a high rating on sharpness. The Widex devices (A and B) have relatively more ‘fullness’.

Technological aspects other than amplification rationales may have an impact on the perception of ‘distortion’ and ‘tube sound’. It is likely that modern digital signal processing algorithms introduce distortion, but factors determined by audiological principles, such as compression speed, can also have a large impact on perceived ‘distortion’, as well as ‘tube sound’. Furthermore, the hearing-aid acoustics related to venting can also contribute to especially the perception of tube sound due to the direct sound path.

In conclusion, the availability of sound quality profiles allow for the formulation of specific goals for sound quality of future devices, while the evaluation methods used here may be used to quantitatively test whether the goals have been achieved.

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