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A study of reliability and response patterns in self-administered audiometry for adult first-time hearing-aid users

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Introduction

The potential benefits of out-of-clinic diagnostics are manifold: It may be used to alleviate clinically trained personnel where resources are scarce, it may reduce the need for travel and it allows for increased privacy and discretion for the potentially hearing impaired, who may see a self-administered hearing test as the first step toward accepting the need for a hearing aid. Many smartphone applications for hearing diagnostics are currently available. However, as reported e.g. by De Wet Swanepoel (2014) the dependency of a specific tablet or smartphone platform, such as iPhone, may cause inconvenient limitations.

Hypothesis

The purpose of the present study is to

1) develop a test paradigm for relevant out-of-clinic tests,

2) get direct experience with relevant platforms,

3) investigate out-of-clinic results for a case hearing test (the absolute threshold as a start) with comparable in-clinic-results, and

4) assess the user experience with the out-of-clinic mock-up system.

Methods

The method comprises the development of a customized software platform, which will allow for later inclusion of other tests, such as those outlined by Sanchez-Lopez (2018) that are currently under development in the BEAR project. The different out-of-clinic scenarios under consideration are shown in Figure 1.

	Waiting Room	Public Library	Living Room	Retirement Home
Patient alone	✉ 💬 📱 🔊	✉	✉ 💬 📱	
Patient with skilled caretaker			📱 🔊 🎥	💬 📱 🔊
Patient with next-of-kin	📱 🔊 🎥	📱 🔊 🎥	📱 🔊 🎥	📱 🔊
Patient remotely with audiologist			📱 🔊 🎥 💻	📱 🔊 🎥 💻

Written on paper ✉	Written on screen 📱	Spoken in person 💬	Spoken audio recording 🔊	Spoken video recording 🎥	Video call 💻

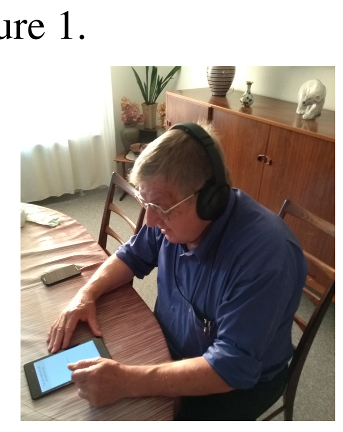

Figure 1. Out-of-clinic diagnostics scenarios with illustration of different means of instructing the user and example of test subject alone in living room.

The accuracy of the procedures in real-life scenarios is determined by comparing the outcome with clinically determined audiometric measures. System Usability Scale (SUS) data according to ISO 9241-11 is collected and brief interviews regarding how the test subjects manage the test are performed after the test session.

Software platform

A tablet-based software application was developed using Unity, a platform mainly for producing computer games, but also used in a gamification approach to hearing-aid tuning as described by Eastgate (2016). The test execution flow of the implemented application is outlined in Figure 2.

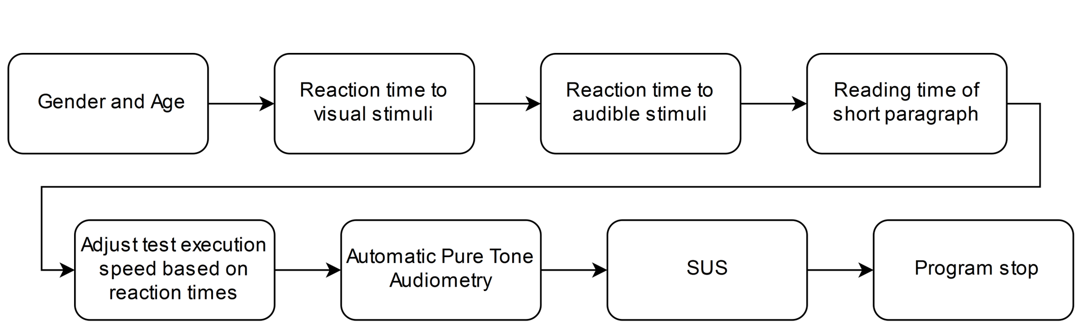

Figure 2. Test execution flow implemented in application

Hardware characteristics

The use of wireless (Bluetooth) headphones reduces the uncertainties of the tablet or smartphone hardware significantly, but the codec may still affect performance. For example, the older SBC standard, used in the Bose QC35II headphone is limited by its resolution at low signal levels and thus is less than ideal for measuring pure-tone thresholds near normal hearing level. Here the newer AptX codec used e.g. in the Sony WH-9000N performs better. However, the tested Sony headphone suffer from distortion issues at 2-4 kHz for the high sound pressure levels.

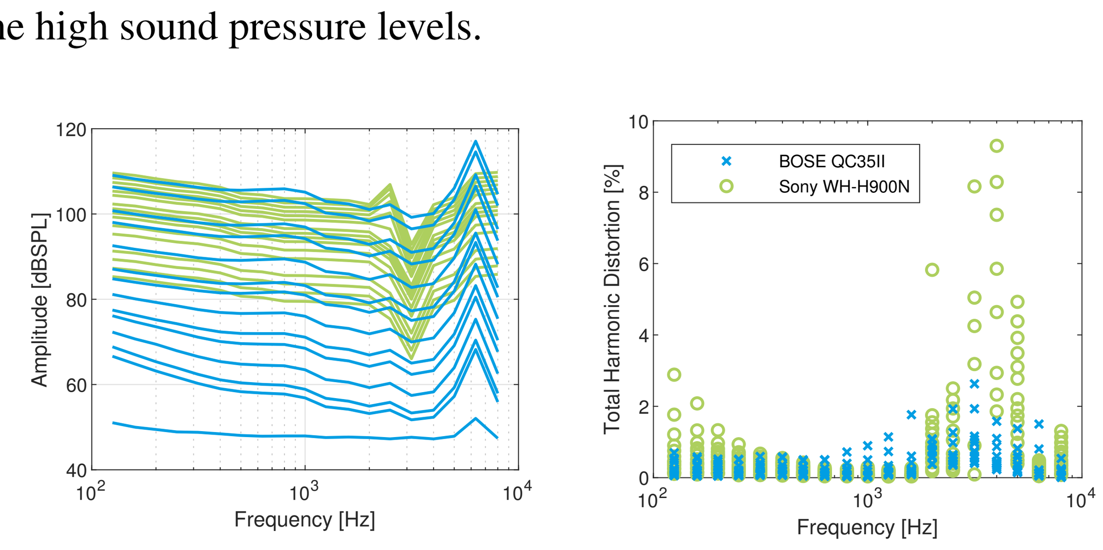

Figure 3. Frequency responses and Total Harmonic Distortion (THD) measured in IEC 318-1 type 1 artificial ear measured at a signal level of -6 dBFS at all available Bluetooth volume steps.

Ambient noise attenuation

Figure 4 shows an example of the active and passive noise attenuation capabilities of a proposed headphone. The measurements were made in an anechoic chamber using a head and torso simulator and a 40 channel loudspeaker array to reproduce different sound fields as shown in Figure 5.

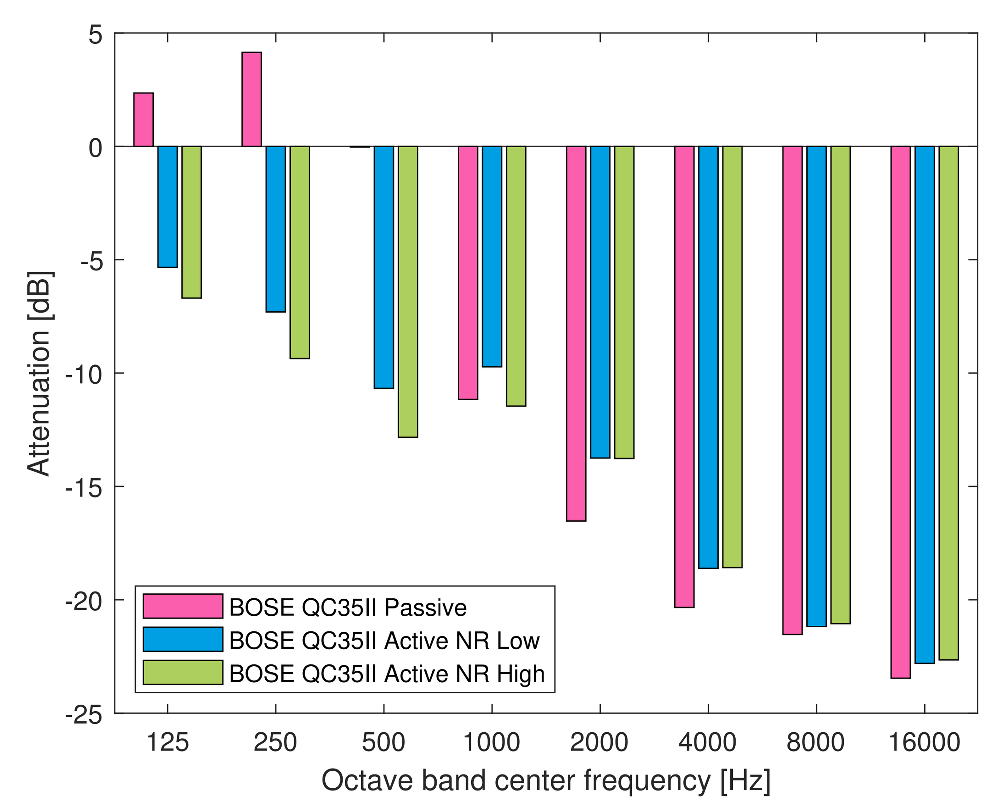

Figure 4. An example of the active and passive noise attenuation capabilities of one of the proposed headphones.

This approach was chosen to be able to perform repeatable comparisons of the headphone performance in realistic sound fields, where especially active noise reduction may yield different results compared to standard measurements using pink noise in a reverberation chamber.

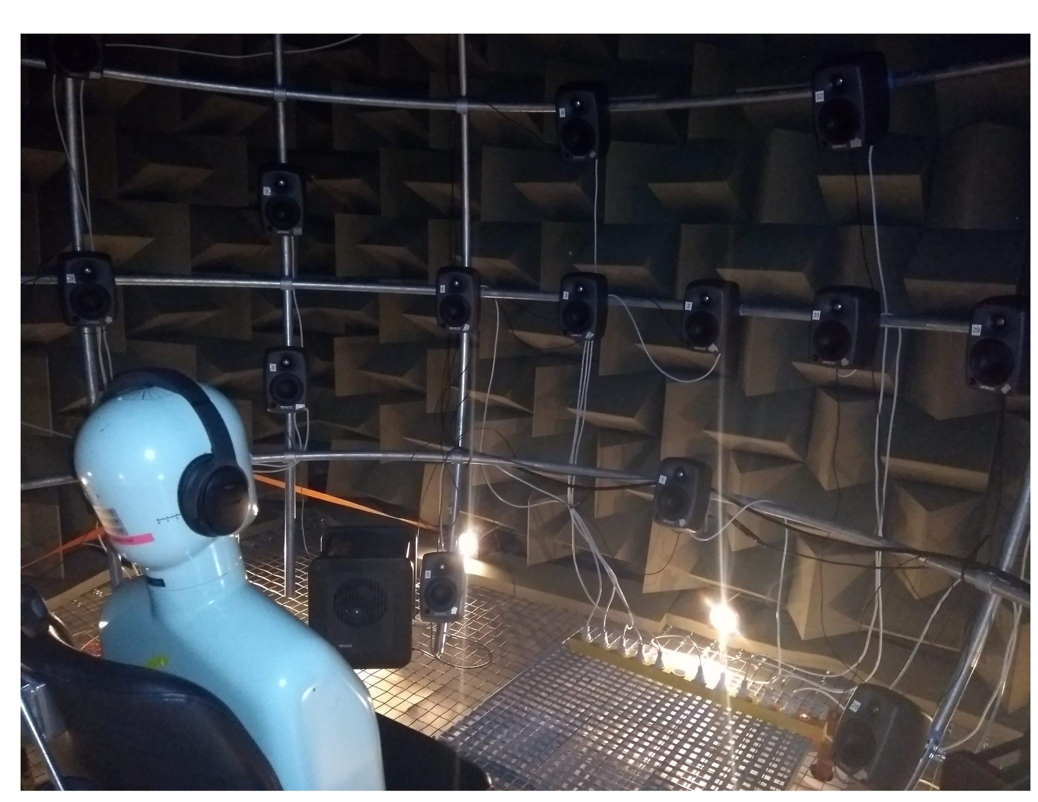

Figure 5. Test setup for characterisation of headphone attenuation

After characterisation of the test equipment a typical use environment is studied and described.

Environment

Measurements of the background noise levels during typical test sessions exhibit large natural variations switching between relative silence, small talk, coughing and spoken announcements.

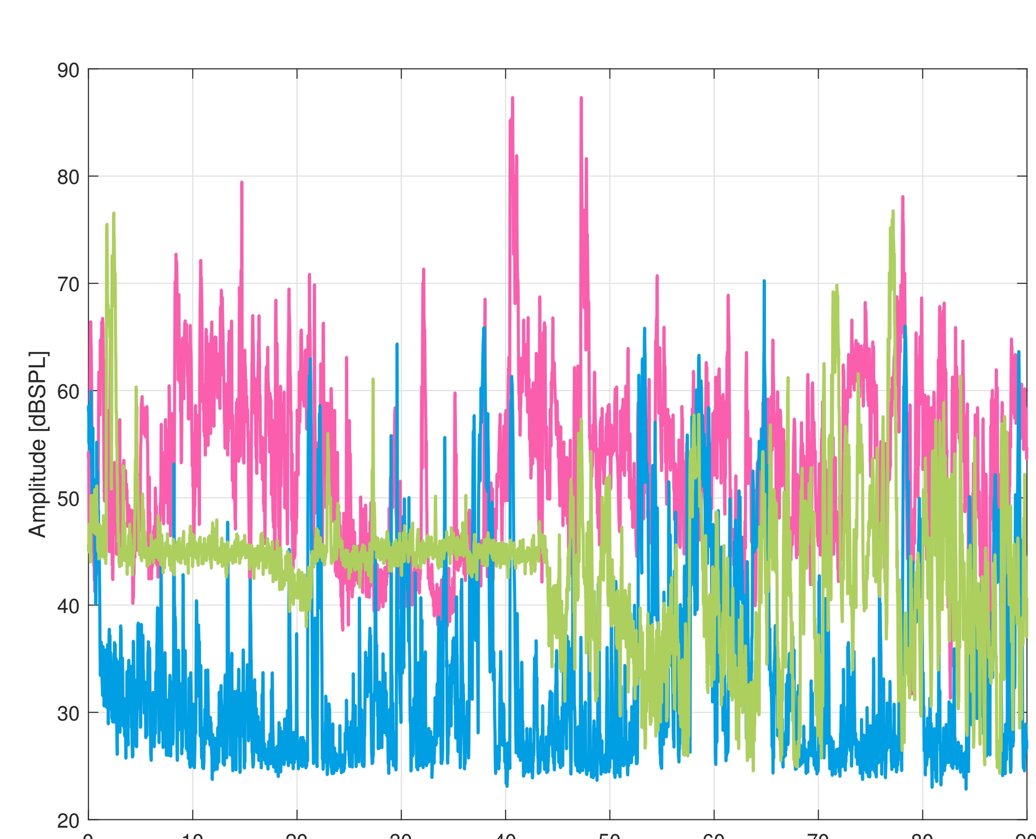

Figure 6. Examples of typical background noise levels.

The short bursts of intense noise, as well as the longer periods with sustained medium levels indicate that additional measures such as noise monitoring and discarding false negatives during the test may be warranted.

Subjects

The inclusion criteria for test subjects are adults without prior hearing-aid treatment, and a maximum hearing loss of 60 dB as an average over 500 Hz, 1 kHz, 2 kHz and 4 kHz. It is the goal to get data from more than 32 test subjects in two different scenarios.

Results

Pilot data has been collected for 8 subjects (16 ears). Figure 7 shows audiometric data from 4 subjects without hearing loss. Since ISO 389-8 specifies the RETSPL for only specific circumaural headphones, a study according to ISO 389-9 could prove beneficial.

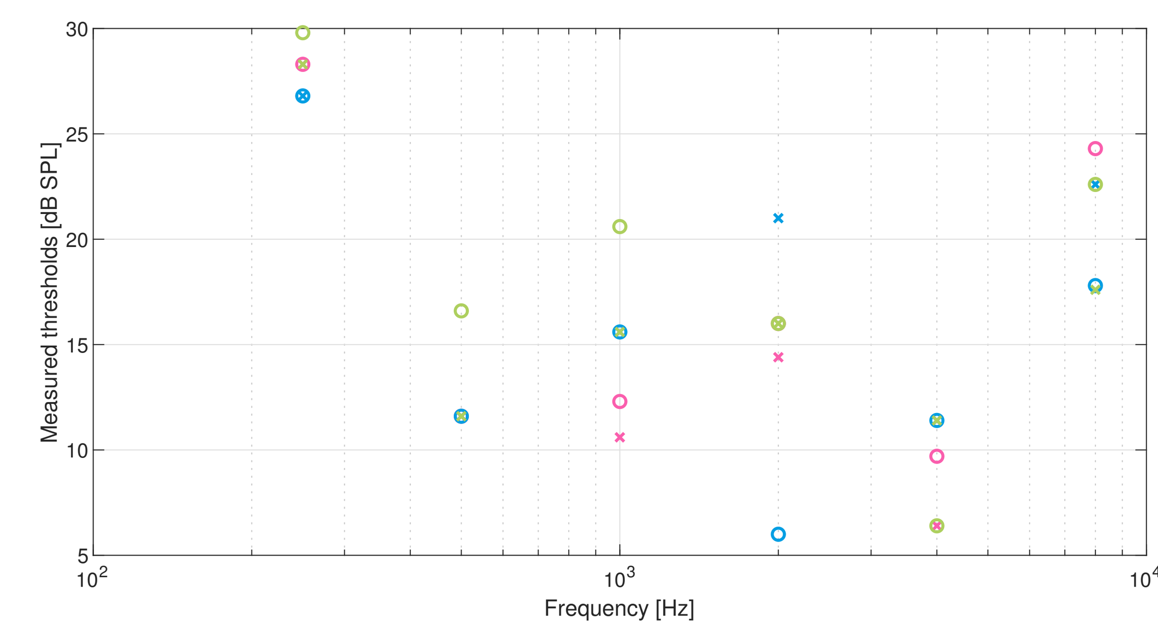

Figure 7. Measured threshold data of 4 subjects (8 ears) using the custom-made test system.

In addition to comparing the measured thresholds with clinically obtained results, a parallel study of the test-retest reliability is ongoing. Figure 8 shows a comparison of threshold data collected using the platform with more than 1 month between trials.

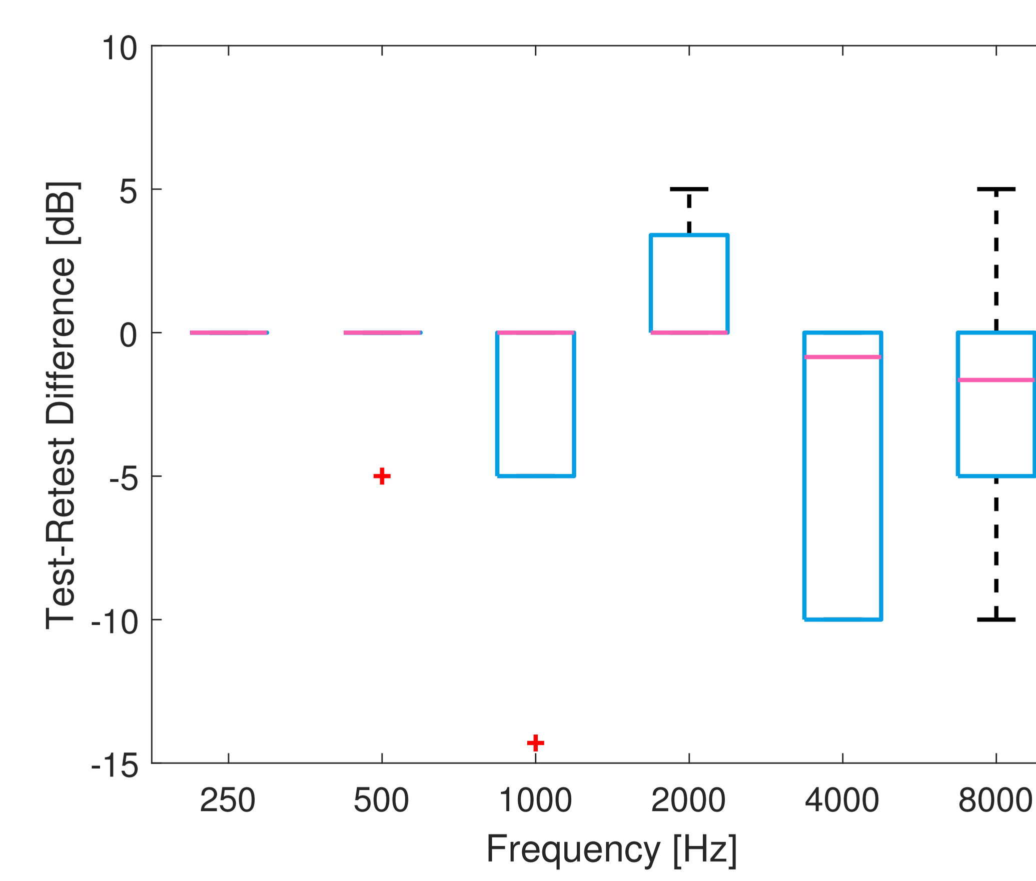

Figure 8. Measured test-retest threshold data of 4 near normal hearing subjects (8 ears) using the custom-made test system.

The larger deviations at higher frequencies may in part be caused by frequency response variations due to fitting and refitting. However, it is also quite probable that there is an influence from the signal processing of the used headphone, when playing back high frequency pure tones near normal hearing threshold.

The collected SUS scores for 8 users range from 52.5 to 92.5 with a mean of 76.9. This may be interpreted as "Acceptable" on an acceptability scale or between "Good" and "Excellent" on an adjective rating scale according to Bangor (2009).

Initial settings of test execution timing parameters yield an average test time for 6 frequencies on 2 ears of 13-19 minutes with an average of 15.2 minutes.

Conclusion

A tablet-based custom-made test system that allows audiometric evaluation in an out-of-clinic setting has been developed. Further studies are needed to verify the suitability in other environments.

Acknowledgements

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