Automated Pure-tone Audiometry Software Tool with Extended Frequency Range

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ABSTRACT

In research institutes and other areas it is necessary to check the hearing of test subjects for listening tests (e.g. for assessing the quality of audio processing algorithms etc.) by measuring pure tone audiograms. Often, neither a necessary skilled operator nor a special audiometer for high frequencies (>8 kHz, important for the evaluation of many audio processing algorithms) are available. As an alternative, a software program for automated audiogram measurements is presented here. This new type of software runs on a standard PC with a high-quality sound card and audiometric headphones and is operated by the test subject him/herself (self-screening). The implemented adaptive procedure allows fast standard audiogram measurements including high frequencies up to 16 kHz. The challenges with respect to dynamic range and calibration are discussed.

1. INTRODUCTION

For assessing the quality of audio processing algorithms and for other listening tests, e.g. to evaluate the quality of loudspeakers, it can be necessary to check the hearing of (potential) test subjects. The pure tone audiogram evaluates the individual hearing threshold levels for defined frequencies, i.e. the lowest level of a pure tone which can be perceived. In clinical environments most often audiometers are available which need a skilled operator for manual operation. A lot of audiometers allow measurements only up to 8 kHz, which is (when combined with speech-discrimination, evaluated by, e.g. speech intelligibility tests) sufficient to give information e.g. about the indication of a hearing aid. For the evaluation of many audio processing algorithms, however, frequencies above 8 kHz are important as well and thus checking the hearing threshold levels at higher frequencies is necessary. In research institutes, an automated system operating without a manual clinical audiometer and a skilled operator would be welcomed.

The only automated, patient-controlled threshold measurement systems available are the *Otogram*™[1] and *AMTAS*®[2], both of them only allowing standard pure tone audiogram measurements up to 8 kHz. To our knowledge, no automated system with an extended high frequency range is available on the market today.

2. HARDWARE SETUP

The presented software runs on a standard PC with a high-quality sound card (24 bit D/A, low noise headphone output with capability to drive low impedance headphones). No further hardware of a clinical audiometer is necessary. As headphones, we recommend to use the circumaural Sennheiser HDA 200, best suited also for automated audiogram measurements. The headphone can be used by the test person her-/himself easily and has a very high passive attenuation which makes the noise level in the measurement chamber/-room not as critical as with open earphones. A quiet room fulfilling at least NR 10 (Noise Rating, developed by the International Organization for Standardization (ISO), e.g. the laboratory described in [3]) is recommended.

3. MEASUREMENT PROCEDURE

The measurement procedure in the software tool is based on a standard ascending procedure for measuring pure tone audiograms (based on Hughson-Westlake procedure, [4]): A pure tone of a certain frequency is presented with increasing level, starting at a level below the assumed hearing threshold. At the moment when the tone is perceived, the subject has to push an answer button (or give a sign). This is repeated one or two times, until the threshold is rated as determined reliably by the operator. Then it will be switched to the next frequency.

In the automated measurement procedure of this software, the number of trials for one frequency is increased and the measurement at that frequency will be repeated until two answers lie within a defined margin of deviation to be considered valid. A short pause of random length follows the user's answer before the next test tone presentation is started, in order to avoid errors by accident or any attempt of deception.

The measurement starts at 1 kHz (if selected) and goes downwards. After the presentation of the lowest selected frequency, frequencies starting from 1 kHz will be measured upwards.

Before each measurement, a simple headphone test is run to make sure that the headphone is placed correctly on the head. For this purpose, the words “left” and “right” are presented successively by the left and right speaker of the headphone, respectively. This way, the user can check the correct position of the headphone him/herself.

The measurement itself is presented for the test subject as a simple task as shown in Figure 1.

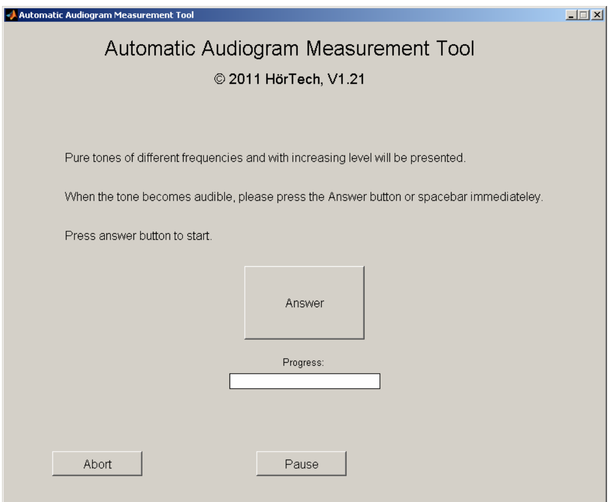

Figure 1 Screenshot: Display during measurement.

A huge variety of parameters (e.g. setting the pause time, steps and time in which the level increases) can be changed by the expert user. This customization makes it possible to adapt the measurement procedure to individual requirements, depending on, e.g.: Available measurement time, desired precision, response time of subjects, desired security to avoid errors and any attempts of deception, expected hearing loss.

To our experience, the time required for one measurement is similar compared to a manual measurement performed by an experienced audiologist. A complete measurement of all 15 frequencies and for both ear needs 11 min. on average. Other procedures, including very efficiently implemented designs (e.g., Békésy-tracking, 3-AFC, [5]), can offer higher frequency resolutions at the cost of much longer measurement times.

4. DISPLAY OF RESULTS

Figure 2 shows an example of a measurement result. Shown are:

- Date, start time and duration of the measurement, and the configured parameter settings which have been applied for that measurement
- The audiogram data for the left and right side, showing the results:
  - hearing threshold level in dB HL (Hearing Level) (last answer)
  - V – hearing level beyond this level: during the measurement the maximum possible output level for this frequency has been reached and no answer was given, which suggests that the hearing threshold level is higher than this level
  - ? – inconsistent answers: The difference between the last two answers is higher than the defined deviation and the maximum number of trials has been reached.
  - Two reference hearing threshold levels (“Limits”, user definable)

The limits are freely user-defined to have reference hearing threshold levels, e.g. as orientation from mean hearing losses of a certain age (e.g., from data collected in [6]). Commonly used definitions of “normal hearing” use a pure tone average of four frequencies (0.5, 1, 2, 4 kHz) of the better ear with a limit of 25 dB HL [7]. This does not include any strict and more differentiated definition with respect to the higher frequencies. Differing from the standard, where the thresholds of the left ear are plotted on the right side of the screen and the level axis ranges from -10 to 120 dB HL, the display can be adapted for a clear and practical arrangement of the results.

5. RETEST RELIABILITY

Measurements of 12 test subjects with one repetition on a different day show a small test-retest standard deviation of 4 dB. 93 % of the differences for the repeated results are smaller than or equal to the used level step of 5 dB. A systematic frequency dependency cannot be seen in these data. Other studies suggest that differences between automatically measured thresholds and thresholds measured manually by audiologists are similar [2].

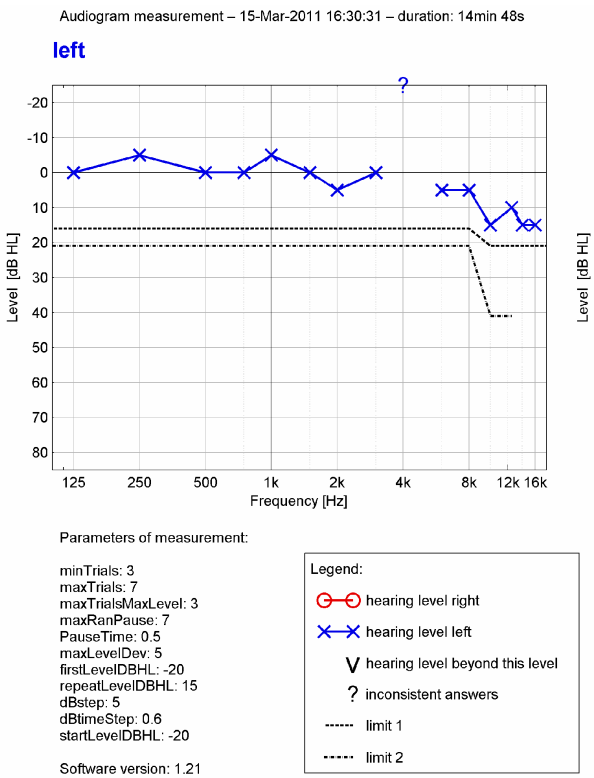

Figure 2 Screenshot showing example results

6. CHALLENGE OF DYNAMIC RANGE, CALIBRATION AND REPEATABILITY

ISO 389-7:2005 [8] defines the reference threshold of hearing to measure hearing thresholds with pure tones in a free field, derived from mean values collected with normal hearing subjects. Pure tones are presented through a loudspeaker with a defined level (dB SPL), measured at the center and in absence of the head. Figure 3 shows the sound pressure values (dB SPL) for each frequency listed in the standard which are necessary to achieve 0 dB HL.

For ISO 389-8:2004 [9] (high frequencies in ISO 389-5:2006, [10]) the reference thresholds of hearing have been determined for headphone listening by comparing headphone and free-field hearing thresholds. The standard defines the calibration of the headphone using an IEC 318 artificial ear. Figure 4 shows the result of a calibration using the definition of the standard for the HDA-200 headphone. Shown are the values of hearing level (dB HL) for each frequency at (theoratically) 0 dB FS output of the soundcard at a chosen calibration. Thus, the maximum possible levels in dB HL for this calibration and each frequency can be directly seen.

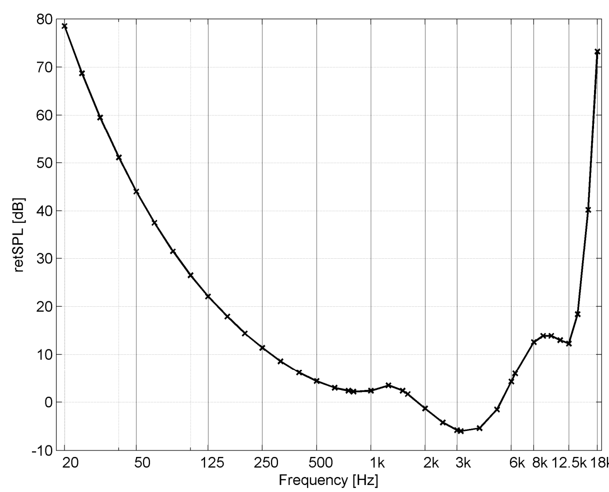

Figure 3 Reference threshold of hearing for free-field pure tone audiometry, as defined in ISO 389-7:2005 [8]

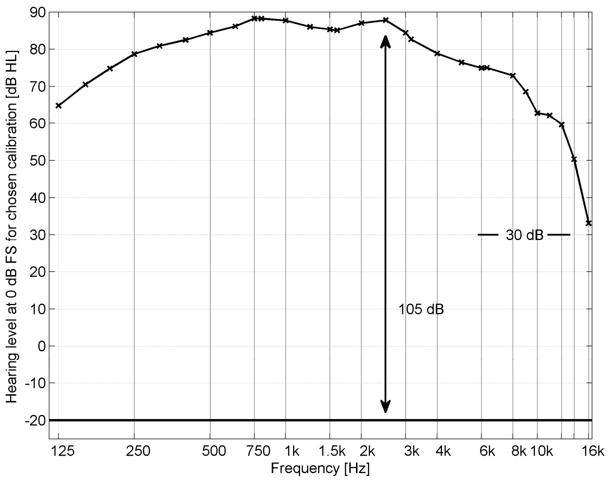

Figure 4 Measured reference threshold of hearing for headphone HDA-200 at 0 dB FS output of sound card

Measuring hearing threshold levels at high frequencies (> 12.5 kHz) requires a high dynamic range of approx. 55 dB to present the same hearing level for all frequencies. Deciding on a lowest presentation level of –20 dB HL and allowing -105 dB FS as the lowest output of the soundcard for this level leads to a maximum hearing level of approx. 30 dB at 16 kHz. Starting at -10 dB HL (as standard clinical audiometers do) and allowing a maximum digital attenuation of -115 dB FS lead to a maximum hearing level of 50 dB at 16 kHz. To achieve even higher dynamic ranges, analogue attenuation (e.g. using a programmable attenuator) would be necessary. For the highest frequencies, short wavelengths of the pure tones can introduce variance in the measured thresholds caused by small differences in the positioning of the headphones on the head. Systematic investigations of this issue have not been carried out yet.

7. SUMMARY

A new software tool for automated pure tone audiogram measurements with extended high frequency range was presented. A standard PC with a high-quality sound card and audiometric headphones (and no clinical audiometer equipment) is needed. The software is operated by the test subject him/herself (self-screening). The implemented adaptive procedure allows fast standard audiogram measurements also for high frequencies up to 16 kHz. Results of 12 test persons showed a high retest reliability. Other studies suggest that the differences between automated measured thresholds and thresholds manually measured by audiologists are similar. It is planned to determine this by comparing the presented software procedure with different common measurement procedures. Due to the strong frequency dependency of the hearing threshold the dynamic range for the extended high frequencies remains a challenge. Repeatability of the highest frequencies needs to be further investigated.

8. REFERENCES

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