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Technical Note

Effect of headphone position on absolute threshold measurements

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ABSTRACT

Pure-tone audiometry (measurement of absolute thresholds using pure tones) is the main test for the diagnosis of hearing loss. The aim of the present study is to determine whether the headphone placement over a listener's ears has an influence on pure-tone audiometric tests, for a large frequency range, for Sennheiser HD600 and Telephonics TDH39 headphones. Audiograms (with 1 dB step, and including 10 frequencies up to 14 kHz) were performed several times on normal-hearing subjects, for different – or not different – headphone positions (allowing to dissociate between effects of headphone position and cognitive factors). Globally, the results seem to indicate that the reliability without headphone removing was quite close to the one observed with removing. The influence of removing did not appear more crucial for high frequencies. The rare frequencies for which a removing effect was seen seem to be function of the headphone model. Finally the results were quite different among the subjects.

1. Introduction

1.1. Reliability of hearing threshold measurements

Pure-tone audiometry consists in measuring absolute hearing thresholds by using pure tones and is used as a primary diagnosis of hearing loss. It can be accomplished by measuring the Minimum Audible Field (MAF) for stimuli presented with loudspeakers or the Minimum Audible Pressure (MAP) for stimuli presented with headphones. In the latter case, the headphone model has to be chosen with care.

Several studies have compared the reliability of hearing thresholds as a function of the headphone type [1–7]. In these studies (which used different step precisions, from 1 to 5 dB), reliability was observed with a test–retest method: subjects' thresholds were measured, then the headphone was removed, then replaced, and new thresholds were measured. It has been shown that supra-aural headphones were less reliable than circumaural headphones [4]. Several studies reported supra-aural headphones to be less reliable than insert earphones [6,7], while other studies showed the same variability with supra-aural and insert earphone [2,3]. In addition, some studies showed that the cushions themselves could have an influence, independently of the headphone model and type [8–10].

1.2. A high frequency specific issue?

Some studies showed that the auditory thresholds were less reliable in high frequencies, and measurements of acoustic level in subjects' ears even showed that above 8 kHz, standing wave patterns create large variations at different points within the ear canal, and that a specific high-frequency audiometer was required, including a feedback in-ear microphone [11–14].

On the contrary, [15] indicated that the intra-subject reliability of threshold estimates should be nearly the same at both the low (0–8 kHz) and the high (8–16 kHz) frequency regions. Authors explained that conventional headphones reduce the size of the standing wave ratios compared with a hard wall termination. An additional factor was the steeper slope of the psychometric function at the higher frequencies. The combination of these factors produced a standard deviation for threshold estimates that was only about 1 dB larger at the high than at the low frequency region.

1.3. Two factors explaining the global reliabilty

Actually, there are at least two explanations for limitation of threshold reliability [11]:

(i) The "threshold variance", determined by the number of trials, the slope of the underlying psychometric function (possibly different in low and high frequencies [15]), the psychophysical procedure, and the consistency of the

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subject's attention and criterion. This variance is between 1 and 3 dB according to previous studies [16,17] using 1-dB step-size audiometry.

(ii) The "fitting variance" concerns differences in earphone placement. At high frequencies, earphone placement or fitting may alter the effective geometry of the ear canal for a given subject, resulting in large changes in effective SPL. This fitting variance is the consequence of the scattering of HPTF with headphone position: the HeadPhone Transfer Function (HPTF) describes both the headphone response and the coupling to a listener's ear. It has been shown that slight modifications in the headphone placement can result in large spectral (>9 dB) differences, especially in high frequency [18–22]. Moreover the modification of timbre introduced by these differences were audible with pink noise and music, for several different headphone models [23].

1.4. Variability specifically due to headphone positionning

Most of test–retest (with systematic removing of headphone) experiments cited above have mixed the two contributions "threshold variance" and "fitting variance". Indeed, when only two audiograms are realized, the effect of headphone repositioning is merged with cognitive factors, procedure validity, etc.

In order to separate between "threshold variance" and "fitting variance", three audiograms have to be measured: two with the same headphone position (the difference between these measurements involves only "threshold variance"), and a third with an other headphone position (the difference between this third measurement and the two other ones involves both "threshold variance" and "fitting variance").

Few studies have separated the two contributions by repeating the threshold measurement both with and without headphone replacement. Two of them, using insert earphones, found an effect of earphone replacement [11,24]. Hickling [5] showed that the removal and replacement of TDH39 supra-aural headphone significantly reduced the reliability of 6 and 8 kHz thresholds in comparison to repeated threshold measurements for the same headphone position (but no effect at 1 and 2 kHz). However, only these four frequencies were under test. Erlandsson et al. [7] and Gauz et al. [25] both compared auditory thresholds obtained when a circum-aural headphone was repeatedly replaced to thresholds obtained when the headphone position was fixed. Erlandsson et al. [7] reported a significant effect of circum-aural headphone replacement on threshold measurements but Gauz et al. [25] reported no such significant effect.

1.5. Summary

From all these previous works it can be seen that:

- Studies exhibited large differences in their measurement methods and most of them consider a 5 or 10 dB precision. As a consequence, results are often contradictory and do not enable to really know if circumaural headphones are more or less reliable than supra-aural headphones.
- Most of the studies used only one retest (with headphone repositioning), and did not enable to draw a global conclusion about the effect of the headphone placement independently of the "threshold variance".
- Most of the studies tested frequencies up to 8 kHz (however few papers tend to indicate that positioning reliability would be more problematic in higher frequencies, but counter-arguments might be found among this literature [15]).
- In addition, the circumaural headphone HD600 is nowadays often used in psychoacoustics experiments and a recent study [23] has shown that modifications of the position of this headphone led to audible changes. However no study has specifically studied the threshold reliability with this headphone.

Taking all these considerations into account, the present study aimed at measuring auditory thresholds with high precision (1 dB step) on a large frequency range (from 125 Hz up to 14 kHz) using both Sennheiser HD600 (circum-aural) and Telephonics TDH39 (supra-aural) headphones, with and without headphone repositioning. Threshold variability was then investigated by comparing the audiograms obtained on both identical and different headphone positions, and enabled to separate between "threshold variance" and "fitting variance".

2. Material and method

2.1. Audiometry procedure

A modified ANSI procedure [26] was used. The audiometry included measurements at octave intervals from 250 Hz through 8 kHz, and additional thresholds were tested at 125 Hz, 6 kHz, 11 kHz, and 14 kHz. We used the octave intervals from 250 Hz through 8 kHz because they are used in clinical audiometry (according to ANSI). Several frequencies were added to expand the measurement range towards the low and high frequencies (125 Hz, 11 and 14 kHz respectively). Threshold exploration was carried out by presenting pulsed tones lasting 2.5 s. The level of successive presentations was determined by the preceding response: in the original ANSI recommendation [26], each failure to respond to a signal leads to successive increases of 5 dB steps until the first response occurs. The intensity is then decreased by 10 dB and another ascending series is begun. In this study, a higher precision was seeked. The algorithm consisted then of a series of three bracketing procedures, each providing progressively smaller step sizes to finally result in threshold responses with 1 dB resolution. The initial bracketing series (Series 1) used step increments of up 5 dB, down 10 dB to quickly bracket the threshold level to within 10 dB. Subsequent bracketing series used step sizes of up 2 dB, down 5 dB (Series 2) and up 1 dB, and down 2 dB (Series 3). Final threshold was defined in Series 3, as the lowest hearing level at which responses occur in at least one-half of a series of ascending trials, with a minimum of two responses out of three required at a single level.

2.2. Participants

Twenty normal-hearing subjects (aged 20–40 years; 7 females and 13 males; mean age = 25.4 yr; SD = 6.3 yr), who were all unpracticed in hearing experiments, participated in the study. Listeners were required to have hearing thresholds $\leqslant$ 20 dBHL in the 125 Hz to 8 kHz frequency range.

2.3. Auditory Listening test

Threshold measurements were made only on the subject's left ear. According to ANSI recommendation [26], the headphone was centered over the ears and its position was adjusted by test subject for most comfortable listening. It is worth noting that some other standards about audiometry [27,28] recommend the tester to adjust himself the headphone placement. However, studies about HPTF measurements showed that a better reproducibility can be obtained when the headphone was placed by the subject himself [29,30].

Subject sat in front of a computer screen in an audiometric booth. The automatic procedure was run using a MATLAB graphical user interface controlled by a PC located out of the booth. Stimuli