Applied Acoustics 93 (2015) 130–139

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Discriminability of the placement of supra-aural and circumaural headphones

Mathieu Paquier *, Vincent Koehl

University of Brest, Lab-STICC CNRS UMR 6285, 6 Avenue Le Gorgeu, 29238 Brest Cedex 3, France

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 20 January 2015
Accepted 30 January 2015
Available online 17 February 2015

Keywords:
Audibility
Headphone
Placement

ABSTRACT

Several studies have shown that differences in the placement of a headphone over a listener's ears could result in large differences in the measurements of the related transfer function (HPTF). Nevertheless, because of – at least – the non-uniform frequency resolution of human hearing system, large HPTF variations at some frequencies do not necessary imply audible consequences, which were not evaluated by past studies. The present study aims at evaluating the audibility of spectral modifications introduced by slight but realistic changes in the headphone placement over a listener's ears.

Recordings were performed by placing/replacing a headphone on a dummy head. Various headphone models were realistically placed eight times each on the artificial head. Music excerpts and pink noise then were played back over the headphones and recorded with microphones located at the entrance of the blocked ear canal. These recordings were then presented to expert and naïve listeners over a single test headphone. The subjects had to discriminate between stimuli standing for different headphone placements using a 3I3AFC procedure.

With the exception of the naïve listeners about one given music excerpt only, subjects were always able to discriminate between the stimuli with respect to their corresponding headphone placement. This indicates that consecutive realistic headphone placements may result in audible differences for the listener. Such a result could raise several issues about the use of headphones for psychoacoustic experiments, especially for multi-session tests.

1. Introduction

Sound reproduction over headphones is used in numerous applications such as sound quality assessment, psychoacoustic experiments, domestic use, audio engineering, binaural rendering, etc [1,2]. When choosing a headphone model according to a specific use, attention is paid to its type and especially to the quality of its transducers. Nevertheless, the coupling between the headphone and the listener's ears is not taken into account apart from the fact that the user might prefer for example a circumaural open headphone over a supra-aural closed one.

The HeadPhone Transfer Function (HPTF) describes both the headphone response and the coupling to a listener's ear. For binaural rendering (based on recordings in ears or synthesis by convolving monophonic signals with HRTFs), the HPTFs can be measured, averaged (for repeated measurements) and inverted to compensate for the headphone influence so that the intended binaural signals are recreated at the listener's ear. According to Pralong and Carlile [3], the equalization needs to be specific to the listener. They found significant inter-individual differences in the 4–10 kHz range when measuring the HPTFs of 10 subjects equipped with the same headphone by using an in-ear recording system. In addition, they showed that the use of non-individualized equalization can lead to errors in localization tasks. On the other hand, Lindau and Brinkmann [4] showed that non-individual binaural recordings were surprisingly perceived as most realistic when compensated using the HPTFs of the recording subject.

Nevertheless, the signals being equalized or not – as it is the case for stereo recordings listened to over headphones and even for numerous cases of binaural reproduction – the scattering caused by differences in the headphone placement over the listeners' ears is not taken into account. However, it has been shown that slight modifications in the headphone placement can lead to large spectral differences, especially above 8000 Hz, where the quarter wavelength of sound is less than the length of the ear canal, and where standing wave patterns create large variations in sound pressure at different points within the canal. Moreover the large spectral difference of blocked-ear-canal HPTF at high

* Corresponding author. Tel.: +33 2 98 01 62 29.
E-mail address: mathieu.paquier@univ-brest.fr (M. Paquier).

http://dx.doi.org/10.1016/j.apacoust.2015.01.023
0003-682X/

frequency is caused by the difference in the coupling of headphone and pinna [5].

Toole [6] reported that these differences are less than 5 dB below 2 kHz, but ranged from 8 to 15 dB above 4–5 kHz. These differences were observed for 3 successive headphone (4 different models) placements on real and dummy heads (3 each). Wightman and Kistler [7] measured the HPTFs on 10 humans for 10 headphone placements and Pralong and Carlile [3] did the same on 10 humans and 1 manikin for 6 headphone placements. Both studies reported that standard deviations of the magnitudes could reach up to 5 dB from 200 Hz to 14 kHz. McAnally and Martin [8] measured HPTFs for 20 headphone placements on 6 human heads. Standard deviations were generally smaller than 2.5 dB for frequencies up to 10 kHz, and were as high as 9 dB above 10 kHz. Kulkarni and Colburn [9] also observed a standard deviation of 9 dB on HPTFs measured for 20 headphone placements on an acoustic manikin for frequencies ranging from 9 to 14 kHz.

The perception of the sound scene might also be altered by HPTF variability if the localization cues are modified as a result. The variability of the HPTF group delays being less than the minimum discriminable interaural time difference [9], the potentially audible modifications of HPTF would be exclusively spectral. Kulkarni and Colburn [9] as well as McAnally and Martin [8] showed that HPTF and HRTF can exhibit similar spectral features. Martin et al. [10] have assessed the ability of listeners to localize sound presented using a virtual audio display that enabled listener-specific equalization based on a single HPTF measurement. They showed that listeners were able to localize virtual sounds with an accuracy equivalent to free-field conditions for eight headphone placements. The headphone placement seemed thus to have a minor influence on this localization task. The variability observed in the HPTF magnitudes (characterized by high-Q peaks and dips in high frequencies) is highly reduced when applying a cochlear filter model on such frequency responses. McAnally and Martin [8] reported that the variability observed in the magnitudes of filtered HRTFs is generally considerably higher than the one observed in the magnitudes of filtered HPTFs. This suggests that the spectral information used by listeners to localize sound is unlikely to be masked by the variability of the HPTF magnitude.

However, even though the variability of HPTFs across headphone placements does not have an adverse effect on localization task, it could still be perceived another way. As an example, since degraded or inadequate HRTF can enhance the "in head" sensation often evoked by headphone listeners [11,12], one can think that modifications of HPTF could have the same effect. As another example, headphone are often used for audiometric testing, and placement variability could possibly affect hearing threshold measurements, which was evidenced several past studies [13,14], but not by Gauz et al. [15]. Besides, at higher levels, a modification of the timbre could also be perceived because of resonances [16].

The aim of the present study is to evaluate whether realistic changes in the headphone placement (i.e. that could occur when anyone places a headphone on his own ears) can lead to noticeable changes in the sound perception. A blind test in which the listener would have to compare stimuli by placing/replacing the headphone over his own head is inherently impossible. So, in the same way as for loudspeaker comparisons [17,18], the different headphone placements have to be recorded beforehand and played back over a fixed headphone. Three different monophonic sequences (one pink noise and two music excerpts) were played over 4 different headphone models and recorded with a dummy head. The omnidirectional microphones were located at the entrance of the blocked ear canal. The recorded sequences were then played back to expert (experiment I with 4 recorded headphone models) and naïve (experiment II with 2 recorded headphone models) listeners on a unique headphone for the whole test. These sequences were also filtered to compensate for the HPTFs of the test headphone. The listener's task was to compare recordings differing only because of the headphone placement at the recording step.

2. Material and methods

2.1. Program material

Three short excerpts were used in this study. The first excerpt was a 3.5 s-long pink noise and two music excerpts were selected from commercially available stereo material. They were extracted from CDs as 16-bit, 44.1-kHz Wave format files. The second excerpt (Ben Harper, 5 s) included drums, an acoustic guitar, a male human voice and choir voices. The third excerpt (Leonard Bernstein, 4 s) included a symphonic orchestra. These two music excerpts were chosen as symphonic music appeared to be more discriminant than popular music for resonance detection [19]. Moreover the masking effect is different with these two excerpts [20]. In order to allow the listener to concentrate on timbral modifications (and not on spatial ones) that could be introduced by differences in the headphone placement, monophonic excerpts were considered. Therefore, the left channels only were kept for the two music excerpts. The spectra of the two music excerpts are depicted in Fig. 1. The 3 excerpts were then diotically displayed to a dummy head using the various headphone models under test.

2.2. Recordings

The recordings were made by using a dummy head (Neumann KU 100) whose microphones (omnidirectional) are located at the

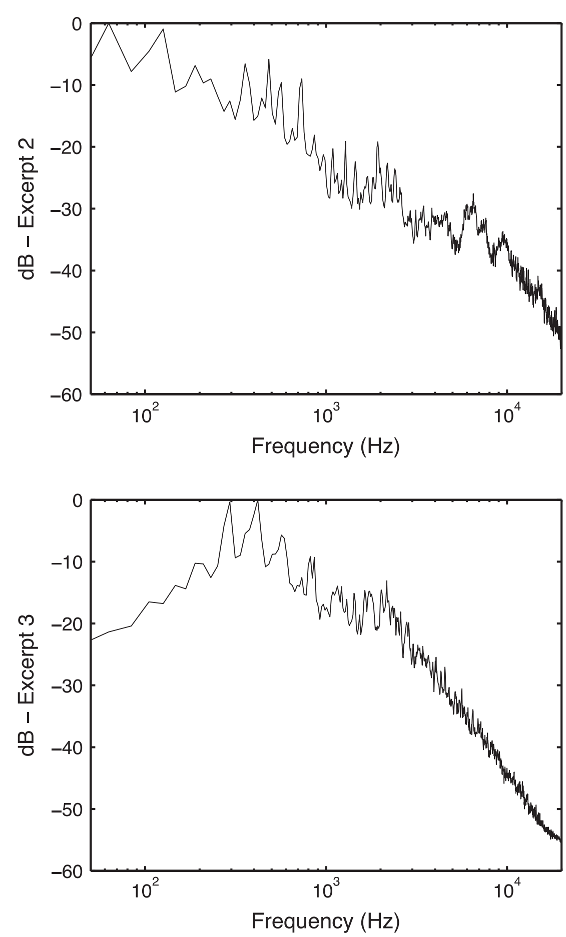

Fig. 1. Long-term spectra (left channel only) of excerpt 2 (Ben Harper) and excerpt 3 (Leonard Bernstein).