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ARTIFICIAL HEADS FOR FREE FIELD RECORDING; HOW WELL DO THEY SIMULATE REAL HEADS?

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INTRODUCTION

The idea behind the binaural technique is as follows: The input to the hearing consists of two signals: Sound pressures at each of the eardrums. If they are recorded in the ears of a listener and reproduced exactly as they were (usually through headphones), then the complete auditive experience is assumed to be reproduced, including timbre and spatial aspects. Normally, during recording, the listener is replaced by an artificial head that has the same shape and the same acoustical properties as an average human head.

The reason why the listener is able to perceive the direction to a sound source, is that the sound on the transmission to the ears is exposed to filterings, corresponding to the particular direction. In most cases, amplitude versus frequency response as well as arrival time are different in the two ears. The hearing is able to "recognize" the filtering and thus determine the direction to the source. A thorough description of the directional hearing is given by Blauert [1].

Model of sound transmission

The free field sound transmission in a real life listening situation can be modelled as sketched in Figure 1. p_4 is the resulting sound pressure at the eardrum and p_3 is the sound pressure at the entrance to the ear canal. p_2 is the "open circuit" sound pressure, and forms together with $Z_{radiation}$ the Thevenin equivalent (Figure 1b). Transfer functions to describe the free field sound transmission is computed from frequency domain representations of the sound pressures, using a reference sound pressure p_1 measured at the center-position of the head, but with the head absent. The transfer function $[P_2/P_1]$ is denoted Head-related Transfer Function (HTF) and describes the directional dependent part of the sound transmission.

The sound transmission at the moment of reproduction by means of headphones can be described similarly. The variables in this second model is $e_{headphone}$ (voltage at the headphone terminals), p_5 (Thevenin sound pressure), p_6 (sound pressure at the entrance to the ear canal), p_7 (sound pressure at the eardrum), $Z_{headphone}$ (replacing $Z_{radiation}$) and again $Z_{ear\ canal}$.

The definitions used, are further discussed in Møller [2], and equations for the total transmission from recording and reproduction chains are given.

Goal of present investigation

The purpose of the work presented in this paper is to collect data of the acoustic properties for a number of commercially available artificial heads and compare with similar data for human subjects. Data for human subjects have been collected in a parallel investigation in our laboratory (Hammershøi et al. [3] and Møller et al. [4]). Data are collected for the artificial heads in order to obtain: 1) Head-related Transfer Functions (HTFs) being $[P_2/P_1]$ covering the whole sphere. 2) The impedance relation at the measuring point of HTFs, described by the directional independent pressure division $[P_3/P_2]$. 3) headPhone Transfer Functions (PTFs) being $[P_5/E_{headphone}]$ for a number of commercial headphones. 4) The impedance relation at the measuring point of PTFs, described by $[P_6/P_5]$. As the data collection is ongoing, the paper presents methods only.

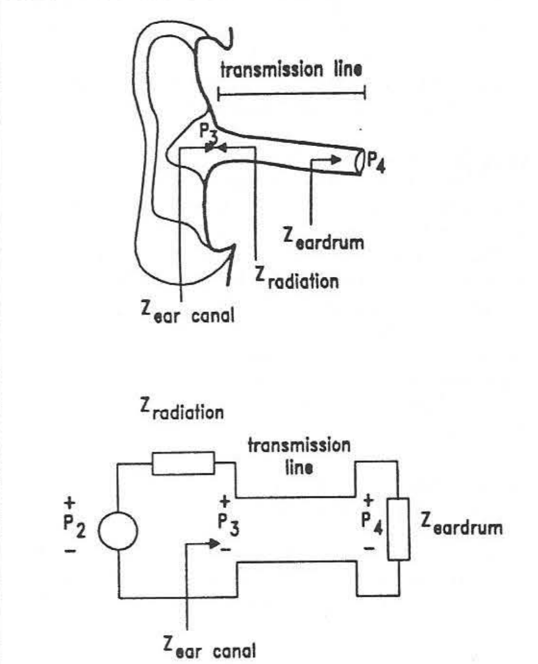

Figure 1. Sound transmission through the external ear - a) sketch of the anatomy and b) an analogue model [2].

METHOD

Measurements were carried out on 8 artificial heads yielding 12 different measurement series. These are listed in Table I, with a few facts of their properties. Free field measurements were made from 97 directions of incidence covering the whole sphere, and headphone measurements were made for 14 different headphones.

Impulse responses were measured by means of MLS technique for the transmission from voltage at the input of the power amplifier to output of the measuring microphone, placed to measure the desired sound pressure (p_1-p_7). HTFs, PTFs, pressure ratios $[P_3/P_2]$ and pressure ratios $[P_6/P_5]$ were obtained through Fourier transformation of the measured impulse responses, followed by appropriate divisions. Subsequent inverse Fourier transformation of the HTFs produced Head-related Impulse Responses HIRs, and inverse Fourier Transformation of PTFs produced headPhone Impulse Responses PIFs.

The method used was similar to the method used for the measurements on human subjects in order to ease comparison (see [3] and [4] for detailed descriptions).

Microphones

Common microphone techniques were used for all heads. A miniature microphone (type Sennheiser KE 4-211-2) mounted in an earplug was used to measure p_2 and p_5.

For the measurements of p_3 and p_6 a probe microphone (B&K 4182) was used, as the probe tip could be placed at the entrance to the open ear canal with minimal disturbance of the sound field. In order to minimize the post processing needed for the determination of $[P_3/P_2]$ and $[P_6/P_5]$, p_2 was also measured with the probe microphone for the directions of incidence for which p_3 was measured, and all p_5 measurements were taken with both microphones.

For the completeness of the datacollection, additional series of measurements for the heads with build-in microphones were taken, yielding either extra sets of p_2 and p_5 measurements or sets of p_4 and p_7 measurements (dependent on the placement of the build-in microphones).

Free field measurements

Measurements were carried out on artificial heads placed in an anechoic chamber. 8 loudspeakers were used, placed in an arc with a distance of 2 m to the center of the head. The artificial heads were rotated to yield measurements from 97 different directions, covering the whole sphere.

p_2 was measured for 97 directions with the miniature microphone. Both p_2 and p_3 were measured for 5 directions (with incidence of the sound wave being front, back, left, right and above) with probe microphones. p_1 was measured with each miniature microphone for each loudspeaker every working day.

Headphone measurements

Headphone measurements were carried out on the artificial head in a damped room for 14 different headphones. 3 measurements were made for each artificial head and each headphone. p_5 was measured with the miniature microphone, and both p_5 and p_6 were measured by the probe microphone.

Measuring system

The general purpose measuring system known as MLSSA (Maximum Length Sequence System Analyzer) was used. Maximum length sequences are binary two level pseudorandom sequences. The basic idea of MLS technique is to apply an analogue version of the sequence to the linear system under test, sample the resulting response, and then determine the system impulse response by cross-correlation of the sampled response with the original sequence. A thorough review of the MLS method is given by Rife and Vanderkooy [5].

For the purpose of measuring at both ears simultaneously, two MLSSA systems were used, coupled in a master-slave configuration by a purpose made synchronization unit allowing sample synchronous measurements. The MLSSA systems were set up with autorange enabled, allowing the best possible utilization of the dynamic range. The sampling frequency of 48 kHz for the MLSSA system was provided by an external clock. Each impulse response computed by MLSSA was based on 16 averaged recordings (called pre-averaging in MLSSA) in order to increase the signal to noise ratio. A MLS length of 4095 samples was used for all measurements, but only the first 768 points (corresponding to 16 ms) were computed and saved.

The stimulus signal from the master MLSSA board was sent to the power amplifier (Pioneer A-616) that was modified to have a calibrated gain of 0,0 dB. From the output it was directed either to the selected loudspeaker in the anechoic chamber or to the headphone being tested.

From the microphone (miniature as well as probe) the signal was sent through a measuring amplifier, B&K 2607. To avoid frequency aliasing, the 20 kHz Chebyshev low pass filter of the MLSSA board and the 22,5 kHz low pass filter of the measuring amplifier were used. Also the 22,5 Hz high pass filter on the measuring amplifier was active.

The overall signal to noise ratio of the complete measuring system with the miniature microphone was typically 70 dB and not below 50 dB for any frequency. For the probe microphone the overall signal to noise ratio was in general approximately 10 dB poorer.

Name	Replication	Microphones
B&K 4128	head, torso, complete ear canal replication and impe dance simulation B&K 4158 and 4159	B&K 4134
B&K Pro Audio	head, torso, no ear canal, no impedance simulation	B&K 4009
Neumann KU80	head only, 4 mm ear canal replication, acoustically terminated to give a flat frequency response for sound with frontal incidence	condenser (serial unknown)
Neumann KU81i	head only, 4 mm ear canal replication, acoustically terminated to give a flat frequency response in a diffuse sound field	condenser (serial unknown)
KEMAR (ear A, B, C, D)	head, torso, complete ear canal replication and impe dance simulation by a Zwilocki coupler (DB100)	B&K 4134
HEAD acoustics Aachen HEAD (without box)	head, shoulders, 4 mm ear canal replication, no impedance simulation	B&K 4165
HEAD acoustics Aachen HEAD (with box)	as above with a box comparable to a torso	B&K 4165
HEAD acoustics Peter Laws replication	The head had not been measured at writing time	
Production of University of Toronto	head, KEMAR torso, complete ear canal replication and impedance simulation	none

Table I. The artificial heads measured.

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