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On the measurement and evaluation of bass enhanced in-ear phones

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ABSTRACT

Measurements of the transfer function of headphones and earphones are made on dummy-heads or on ear simulators. This paper introduces measurement problems of newly designed in-ear phones, often called as micro-driver equipment. These earphones have smaller transducer diameter and are equipped with rubber or spongy material to fit in the ear canal. This coupling may create an increased sound isolation, less sound pressure and a better low frequency transmission to the eardrum. The paper presents subjective evaluation of listeners who evaluated five different kinds of in-ear phones as well as transfer function measurements using a dummy-head. Measurement problems are highlighted pointing on new aspects of a revised dummy-head standard.

INTRODUCTION

At the beginning, transfer functions of headphones were measured on ear simulators. These tubes tried to model the acoustic parameters of the human ear-canal, one side terminated with a microphone, the other with device under test. Standards determined the force of pushing the headphone on the measurement device as well as any other parameters. Nowadays, dummy-heads allow two-channel simultaneous recordings of transmission properties, using artificial pinnae and ear-canal simulators. Furthermore, blocked-entrance ear canal models are on the market for different approaches of measurements.

This paper focuses on objective and subjective evaluation of recently designed in-ear phones. These equipments are called „micro driver”, „bass boost”, „in-ear” or similar. As the name suggests, enhanced bass transmission is the most important feature. Different rubber or sponge extensions are shipped to fit in the individual ear canal. Light weight, good sound isolation are promised. Our goal was to test whether these commercially available types fulfill the customers’ expectations or not.

HEADPHONE LISTENING

During headphone listening we face a special sound field and listening condition [1-6]. The usual crossfeed between the ears is lost. Comfort of wearing the headphone is very important, therefore, often they are fitted with large supra-aural sponge, that is good for long-time comfort but the coupling between ear-canal and transducer is not optimal at all. The air is „snifting” and this results in low-pass filtering of the transmission. The bigger is the distance between head/ear and headphone, the more is the low frequency transmission affected.

Moving of the head does not deliver more information about the sound field because it is moving with the head. This can result in in-the-head localization [1, 4]. On the other hand, small membrane transducers such as earphones and in-ear phones are often uncomfortable, could produce more bass power and overall sound pressure levels at the eardrum.

In case of micro-drivers the membrane is smaller than usual, for having a stronger electromagnetic effect neodymium magnets are used. A very important part is the silicon fitting for mechanical hold and for individual adjusting. If the size does not fit, poor bass transmission occurs and the sound isolation property decreases.

The transfer function of a headphone is defined with the termination. This means, every headphone had to be measured individually on each listener. To avoid this, dummy-heads and/or ear simulators are used. The mounting of the headphone on the head is an important question during measurements. Incorrect occlusion leads to incorrect measurements. This is a question of repeatability/reproducibility of the measurement [7, 8].

Problems may occur in case of very small designed in-ear phones. They were designed to fit in properly into the ear canal, blocking the entire ear canal entrance. This results in a very good occlusion, good quality transmission especially in the bass range and additionally, very effective sound insulation of the environment (Fig.1.).

Figure 1. An example of a micro driver in-ear phone and fitting in the ear canal.

Measurement problems occur by dummy-heads using the blocked-ear canal entrance method. Some manufacturers offer this solution to avoid simulation of ear canal propagation, ear canal impedance (e.g. the Zwislocki coupler). This is based on the observation that spatial information does not require measurement on the eardrums [7-9]. However, this kind of dummy-head design does not allow measurement of earplugs and in-ear phones. Furthermore, dummy-heads having microphones at the eardrum may be not sufficient if the ear canal entrance is too small for the ear phone to fit in. This was the case for the Brüel Kjaer 4128 as well, even the rubber extensions for a "small ear" could not fit in at all.

Measurement equipment

Transfer function measurements of headphones are made on standardized dummy-heads. Our setup uses the Brüel Kjaer 4128 head and torso simulator with microphones placed at the eardrums' positions (Fig.2.) [10].

The maunfacturer provides models with microphones placed at the blocked ear-canal entrance as well [11]. Ear Simulator Type 4157 is primarily intended for frequency response, sensitivity and distortion measurements on earphones coupled to the ear by ear inserts such as tubes, ear moulds or eartips, for example, as used in hearing aids and operator headsets. Artificial Ears Types 4152 and 4153 have been designed for measurements in the audiometric and related fields. They enable electroacoustical measurements on either insert earphones or headphones to be carried out under well-defined acoustical conditions, which are of great importance for the comparability of different designs and the reproducibility of measurements. Head and Torso Simulator Type 4128D is a mannequin with built-in ear and mouth simulators that provides a realistic reproduction of the acoustic properties of an average adult human head and torso. It is ideal for performance in-situ electroacoustic tests on telephone handsets. Head and Torso Simulator Type 4128 C is a mannequin with built-in ear and mouth simulators that provides a realistic reproduction of the acoustic properties of an average adult human head and torso. It is ideal for performance in-situ electroacoustic tests on:

- telephone handsets (including mobile and cordless)

- headsets

- audio conference devices

- microphones

- headphones

- hearing aids

- hearing protectors.

Figure 2. The BK4128 dummy-head and the DZ 9629 pinnae. Note the relatively small diameter of the (non-blocked) ear canal entrance.

Other manufacturers also offer dummy-heads. The HMS II.3 HEAD Measurement System is a Head and Torso Simulator of Head Acoustics in accordance with ITU-T P.58, which specifies the geometry of the head and the acoustic output of the mouth, and IEC 711 which describes an occluded-ear simulator, to which is added an ear canal extension terminated with a simplified pinna [12]. Standard delivery includes ear coupler on the right side only; the left side ear coupler is optional. The ITU-T P.57 Type 3.3 Pinna - meeting the latest ITU-T standard - is a human-like pinna which is suitable for measuring headsets and handsets. It is an option for both the left and right ears of the HMS II.3 and II.4 heads. The ITU-T P.57 Type 3.4 Pinna is a thin-walled simplified pinna which is suitable for measuring headsets and handsets, particularly for applications where the pressure dependent characterization of those devices is needed.

The company GRAS offers the KEMAR Manikin Type 45BA, acquired from Knowles Electronics, is an acoustic research tool which permits reproducible measurements of hearing instrument performance on the head, and of stereophonic sound recordings as heard by human listeners [13]. This head and torso simulator is based on worldwide average human male and female head and torso. The Artificial Ear Type 43 is a complete test jig for acoustical measurements on telephone handsets and earphones. 5 different types of this exist. The Artificial Ear Type 43AC is a complete test-jig for acoustical measurements on earphones coupled to the ear by inserts such as tubes and ear moulds. The Ear and Cheek Simulator represents the section of a head important for realistic reproduction of the acoustic properties of the ear of an average human head. Eight different KEMAR ears are available for the Type 43AG: small – large and left – right in soft and very soft versions are available. The small ears are typical of the pinna sizes of American and European females as well as for Japanese males and females. Large ears are more representative of the pinna sizes of American and European males. The Type 43AG can be used for headsets, hearing aids, circum-aural headsets, mobile phones etc.

System setup

The measurement included objective and subjective evaluation. First, the earphones were measured in an anechoic chamber using the BK 4218 dummy-head and the PULSE 6.5 system (Fig3.). No additional hardware or software was required. The PULSE front-end delivered white noise excitation on the output and collected the response on the input. The excitation is monitored through a feedback from the output to the other input, and the transfer function was calculated and plotted. Spectral averaging of 10 repeated measurements were used for each type.

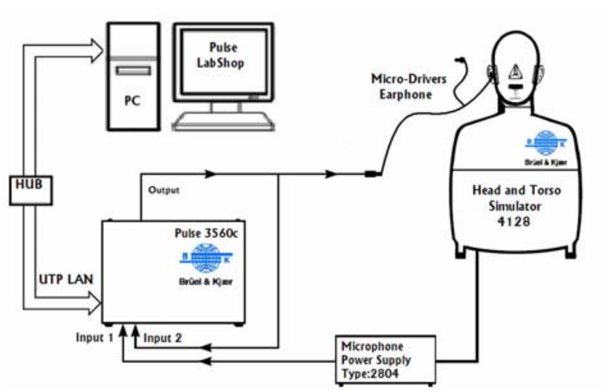

Figure 3. The measurement setup for transfer function measurements.

Five different kinds of micro-driver in-ear phones and a conventional earphone were included in the test. Tables 1-2 show the datasheet given by the manufacturers.

Table 1. Datasheet of the earphones.

Type	Shure E3C	Sennheiser CX300	Creative EP635
Frequency range	n.a.	18Hz-21 kHz	6Hz-23kHz
Sensibility mW@1kHz	115dB	112dB	106dB
Impedance	26 Ω	16 Ω	16 Ω
Weight	28g	12g	12g
Rubber	8 pairs	3 pairs	3 pairs

Table 2. Datasheet of the earphones (cont).

Type	KOSS Spark Plug	Thomson HED 132N	Sony MDR-E818LP (conventional)
Frequency range	10Hz-20kHz	20Hz-20kHz	12Hz-22kHz
Sensibility mW@1kHz	112dB	101dB	108dB
Impedance	16 Ω	16 Ω	16 Ω
Weight	25g	15g	15g
Rubber	2 pairs	3 pairs	-

Figure 4. Shure, Sennheiser, Creative.

Figure 5. Koss, Thomson, Sony.

As part of this session we measured the sound isolation properties as well. With other words, the earphones were used as simple earplugs (without excitation). The dummy-head were placed first in front of the loudspeaker (frontal incidence) and second, from the sides (90 degrees). Figure 6 shows the installation. White noise was played back simulating broad band noise and sound pressure levels were measured with the dummy-head first with then without the earphones at five different frequencies: 500 Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz.

Following the objective evaluation, a subjective listening test was performed by 50 subjects. A CD-Audio disc was played back on a Panasonic Discman in a non-anechoic environment. Subjects were young adults, all male (university students). Each subject selected the best fitting earplug (size and comfort) for each earphone. After mounting it on the earphones they were asked to try all six candidates. They were free to choose the order, loudness, and time for the evaluation. Usually they needed about 30-40 minutes for the evaluation and to fill in the prepared questionnaire.

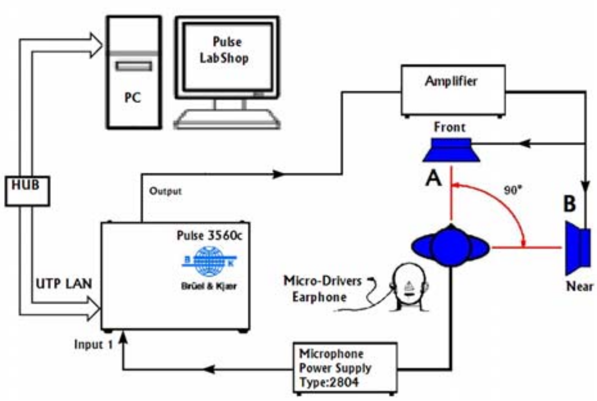

Figure 6. The measurement setup for sound isolation measurements.

RESULTS

Transfer function measurements

Figure 7 shows measured data for six types according to Tables 1-2. Ten measurements without averaging are shown for each type. The conventional type Sony shows larger deviations in repeated measurements below 100 Hz.

By comparing the plots it is clearly seen that all five micro-driver in-ear phone have a quite good low-frequency response. The best are the Sennheiser, Creative and the Thomson. The Koss and Shure types are in some degree behind them.

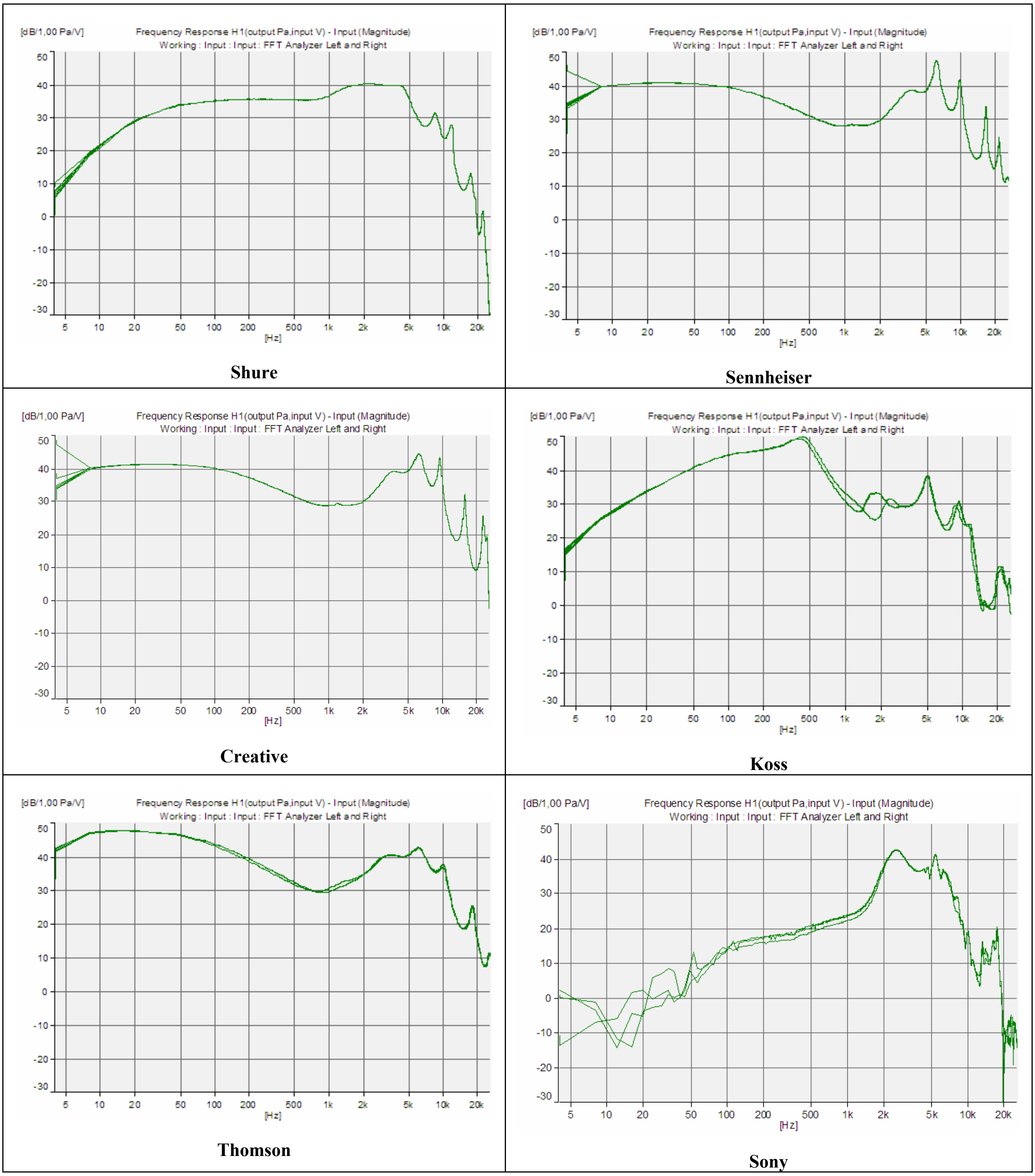

Figure 7. Transfer function measurements of six earphones.

Sound isolation

For sound isolation measurements, all types were used as simple earplugs. We did not search for exact results, but for estimation. Figure 8 and Table 3 show the damping results at „frontal incidence".

Results show that a properly selected rubber fitting results in a good sound isolation in contrast to the conventional type that has almost no isolating effect. Surprisingly, some measurements showed negative values (amplification) that suggest measurement errors. Figure 9 and Table 4 show the same evaluation but for „lateral" incidence.

Sound isolation was also also evaluated by the subjects the same way (see Table 5 later). Results can differ if music playback is active. Users set the volume during listening loud enough to overcome environmental noise especially in traffic situations. Good sound isolation can result in decreased loudness levels and thus, users also disturb less the environment near them.

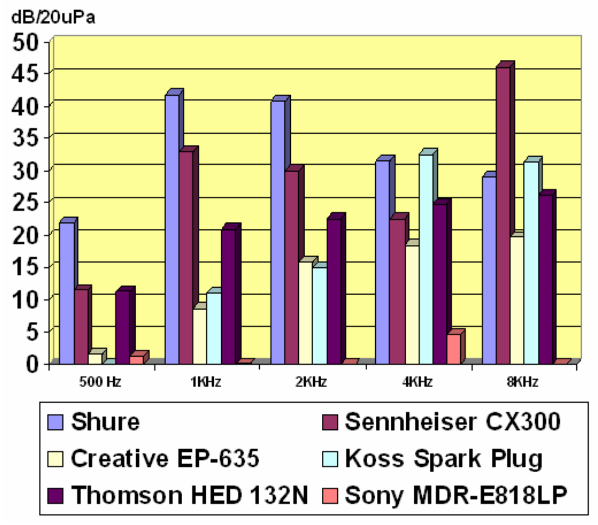

Figure 8. Sound isolation of six earphones at various frequencies at frontal incidence.

Table 3. Sound isolation in dB at various frequencies at frontal incidence

Damping (dB/kHz)	**0,5**	**1**	**2**	**4**	**8**
Shure	22	41,7	40,8	31,5	29
Senn-heiser	11,5	32,9	30	22,5	46,1
Creative	1,6	8,6	15,9	18,5	19,7
Koss	-1,3	11,1	15	32,5	31,4
Thomson	11,3	21	22,6	24,8	26,2
Sony	1,3	0,1	-3,3	4,6	-9,3

Measured damping rates are larger from the side than frontal. The Shure E3C performed the best. The manufacturer shipped this with 8 different sponges for selecting the optimal size for everybody. We have to point out that large measurement differences can appear in repeated measurements. However, all five micro driver types were superior to the conventional type earphone.

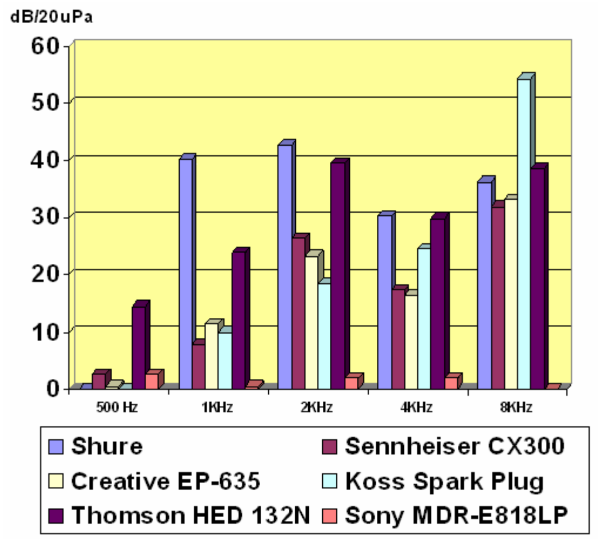

Figure 9. Sound isolation of six earphones at various frequencies at lateral incidence.

Table 4. Sound isolation in dB at various frequencies at lateral incidence

Damping (dB/kHz)	**0,5**	**1**	**2**	**4**	**8**
Shure	-4,7	40,2	42,6	30,2	36,2
Senn-heiser	2,7	7,9	26,4	17,4	31,9
Creative	0,5	11,4	23,3	16,5	33,2
Koss	-0,4	10	18,5	24,5	54,3
Thomson	14,5	23,9	39,5	29,9	38,6
Sony	2,7	0.5	1,9	2	0

Subjective evaluation

Subjects evaluated the devices on a questionnaire by giving points from 1 to 10 (10 is the best) by observing parameters such as „comfort", „bass reproduction", „overall transmission quality", „outer noise isolation". For the latest, the music was stopped and the device was only used as an earplug. No special sound environment was specified, users moved and acted in a standard noisy class room. Only the loudness could be adjusted during test. Average results are shown in Table 5.

The subjective evaluation supports the dummy-head measurements. The Sennheiser and the Creative performed the best. The Koss seemed to be uncomfortable to wear. The most expensive Shure was not welcome at all (neither comfort nor bass transmission). We have to point out, that we selected only one conventional type for comparison. Other models of the same manufacturer or models of different manufacturers could lead to different results.

Table 5. Subjective evaluation of 50 subjects. Averaged results for all devices. The Sony was left out from averaging.

	Com-fort	Bass	Sound isolation	Over-all	Avg
Senn-heiser	**8,03**	**8,25**	**8,53**	**8,38**	8,30
Creative	**8,22**	**8,25**	**8,28**	**8,41**	8,29
Thomson	**7,28**	**7,47**	**7,91**	**7,41**	7,52
Koss	**4,59**	**8,25**	**8,13**	**5,06**	6,51
Shure	**5,41**	**5,50**	**7,59**	**6,38**	6,22
Avg.	6,71	7,55	8,10	7,13	
Sony	4,53	4,38	2,84	5,41	4,29

FUTURE WORKS

Future works mainly include the reconsideration of dummy-heads and measurement standards [14, 15]. Existing models are not very well for measurements like this, because most of the models have blocked-entrance ear canals and these equipments do not fit in at all. Furthermore, non-blocked ear canal entrances can be too small in diameter.

A current work of new ANSI standard for dummy-heads suggests to have different dummy-heads for measurements (with simplified outer geometry and pinnae) and a different, highly individual type for spatial hearing research and binaural recordings (highly detailed and individually optimized using laser scanner or MRI etc.) [16-19].

SUMMARY

Five different in-ear phones were evaluated using dummy-head measurement and subjective evaluation by 50 subjects. We focused on a comparison between objective and subjective evaluation as well as on measurement problems of new designed, micro driver in-ear phones.

Dummy-head measurements showed good transmission in the bass range and sound isolation in contrast to a conventional type earphone. Subjective evaluation supported the measurements and highlighted problems of wearing these earphones comfortable.

Due to enormous measurement setup problems, it is recommended to use ear simulators prepared for newly designed small earphones as well (different size of pinna, ear canal entrances etc.). A new standard for development and manufacturing of dummy-heads is about to form leading to manufacturing new dummy-head models.

REFERENCES

1 J. Blauert, *SpatialHearing* (MIT Press, MA, 1983).
2 S. Mehrgart and V. Mellert, “Transformation characteristics of the external human ear” *J. Acoust. Soc. Am.* **61(6)**, 1567-1576 (1977)
3 H. Møller, “Fundamentals of binaural technology” *Applied Acoustics* **36**, 171-218 (1992)
4 M. Kleiner, B.I. Dalenbäck and P. Svensson, “Auralization – an overview” *J. Audio Eng. Soc.* **41**, 861-875 (1993)
5 K.D. Jacob, M.Jorgensen and C.B. Ickler, “Verifying the accuracy of audible simulation (auralization) systems” *J. Acoust. Soc. Am.* **92**, 2395 (1992)
6 D.R. Begault, *3-D Sound for Virtual Reality and Multimedia* (Academic Press, London, UK, 1994)
7 H. Møller, D. Hammershøi, C.B. Jensen and M.F. Sørensen, “Transfer Characteristics of Headphones Measured on Human Ears” *J. Audio Eng. Soc.* **43(4)**, 203-216 (1995)
8 H. Møller, C.B. Jensen, D. Hammershøi and M.F. Sørensen, “Design Criteria for Headphones” *J. Audio Eng. Soc.* **43(4)**, 218-232 (1995)
9 J.V. Hundeboll, K.A. Larsen, H. Møller and D. Hammershøi, “Transfer characteristics of headphones” *Proc. of 6th Int. FASE Conference*, Zürich, 161-164, (1992)
10 Gy. Wersényi, “Measurement and Evaluation of new design in-ear phones” (in Hungarian) *Journal of Telecommunications* **64(1-2)**, 29-36 (2009)
11 http://www.bksv.com/
12 http://www.head-acoustics.de/eng/index.htm
13 http://www.gras.dk/
14 D. Hammershøi and H. Møller, “Artificial heads for free field recording: how well do they simualte real heads?” *Proc. of the 14th ICA*, Beijing, paper H6-7 (1992)
15 K. Geniut and A Fiebig, “Do we need new artificial heads?, *Proceedings of the 19th International Congress on Acoustics (ICA)*, Madrid, Spain, 2007 /7 pages/
16 T. Hirahara, H. Sagara and M. Otani, “Sound localization with scaled dummy-heads on a TeleHead. *Proceedings of the 19th International Congress on Acoustics (ICA)*, Madrid, Spain, 2007 /7 pages/
17 I. Toshima, H. Uematsu and T. Hirahara, “A steerable dummy head that tracks three-dimensional head movement: TeleHead” *Acoustical Science and Technology* **24(5)**, 327-329 (2003)
18 I. Toshima, S. Aoki and T. Hirahara, ”Advance version of steerable dummy head that tracks human head movement in real time: TeleHead II” *J .Acoust. Soc Japan* **62(3)**, 244-254 (2006)
19 T. Hirahara, “Physical characteristics of headphones used in psychophysical experiments,” *Acoustical Science and Technology* **25(4)**, 276-285 (2004)