



DO WE NEED NEW ARTIFICIAL HEADS?

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ABSTRACT. The binaural recording technology based on an artificial head for the investigation of sound quality was introduced more than 25 years ago. In the meantime, this binaural technology is well established worldwide for a lot of different applications in the field of listening tests on the one side and measuring transfer characteristics of hearing protectors, head phones, telephone systems and others, on the other side. Most of the available artificial heads with respect to the geometrical dimensions are based on the ANSI S 3.36-1985. This standard has used geometrical data which were valid more than 75 years ago. In the meantime, the average dimension of people's head has changed. The question is how important the dimensions and the relationships of head, pinna and shoulder are to each other with respect to listening tests, spatial hearing and the measurement of sound events.

INTRODUCTION

Binaural technology comprises recording of sound by means of an artificial head measuring system. This technology has played an important role during recent years in the field of measuring and subsequently playing back environmental, occupational, product noise as well as music. The reason for the breakthrough of binaural technology in the field of acoustic measurement technologies lies in the capability to record, store and reproduce (all) three dimensional aspects of a sound field. With current artificial head measurement systems recordings can be easily carried out without expenditure of time.

The considerably improved performance of binaural technologies compared with "conventional" recording techniques does not prevent from further scientific discussions concerning the accuracy of artificial head measurement systems. In particular, the discussion is, among other aspects, focused on the accurate geometrical dimensions of the head and ear.

Spatial hearing is strongly dependent on the head-related transfer functions, which in turn are influenced by the geometrical dimensions of head, ear, pinna, shoulder, and torso. The outer ear is a directional filter. The filtering properties of the human outer ear are brought about by diffractions and reflections, depending on direction, caused by the outer geometry as well as by resonances which are independent of direction. These filter properties are very important for source localization and further (binaural) signal processing. However, many investigations showed that there exist numerous individual differences in head geometries causing differences in the perception of noise [1], which make it difficult to derive representative geometrical dimensions for artificial heads.

GEOMETRICAL DIMENSION VARIATIONS OF THE HUMAN HEAD AND HUMAN EAR

Individual variations of head-related transfer functions (HRTF) correspond to variations of geometrical parameters. Since the special structures of the HRTF result in the perception of different sound incidences - especially in the median plane where interaural time differences are of minor relevance - the HRTF are of great importance for sound source localization. HRTFs are strongly influenced by several reflecting and diffracting bodies in a complex way, influenced by main geometrical quantities. The major parameters are the geometrical dimensions of the head, pinna, cavum conchae, shoulder, and torso. [2]

Table 1, 2 and 3 depict differences of human head and ear-related geometrical dimensions. Surprisingly, it can be observed that the anthropometric values differ from anthropometric data base to date base. The variances in the conducted anthropometric surveys point out the difficulty in defining the most representative geometrical dimensions. Table 2 underlines also the remarkable geometrical variations of human head dimensions. The geometrical dimensions of the human head vary considerably in height, breadth, length, circumference and transversal head bow indicated by means of the percentiles. Furthermore, a difference is clearly observable between the male and female head geometry, which consequently suggests the need of two artificial heads matched with the male as well as female geometry. A further aspect is that any possibility of a (systematic) change and shift of anthropometric dimensions as a result of varying “environmental and living” conditions cannot be eliminated. The comparison of anthropometric surveys over the last 100 years suggests a drift to larger human body dimensions.

Table I. - Head-related dimension percentiles of males and females, published in DIN 33402-2: 2005[3] Handbuch der Ergonomie 1985/1975 [4], ANSI S.3.36–1985 [5], International Data on Anthropometry 1989 [6], Burkhard, Sachs [7], Genuit [8]

Reference Body Dimension in mm	DIN 33402- 2: 2005-12/ HdE 1985 [Male, Percentile 50]	DIN 33402- 2: 2005-12/ HdE 1975 [Female, Percentile 50]	ANSI S.3.36- 1985	International Data on Anthropometry (Jürgens, Aune, Pieper 1989)		Burkhard, Sachs (1978)	Genuit (1984)
				Small	Large		
Head breath	155/155	150/149	152	135	160	155	177
Head length	195/192	185/179	191	175	195	188	218
head height	220/229	210/218	224 (menton vertex length)	-	-	232	261
transversal head bow	365	335	-	-	-	-	-
head circumference	570	545	-	505	570	-	-

Table II.- Head-related dimensions of males and females, DIN 33402-2:2005-12 [3, 9]

Reference	DIN 33402-2: 2005-12 Ergonomics: Human Body Dimensions (Part 2): Values						
	Percentile						
Male – Body Dimension in mm	5	50	95	Female – Body Dimension in mm	5	50	95
head breath	145	155	165	head breath	140	150	160
head length	185	195	205	head length	170	185	195
head height	210	220	235	head height	190	210	235
head circumference	545	570	600	head circumference	520	545	570
transversal head bow (from tracion to tracion above head)	340	365	385	transversal head bow (from tracion to tracion above head)	320	335	360

Different head-related geometrical dimensions and proportions can also be stated between different continents or even regions, as shown in table 4, which could justify the claim for “localized”, regional artificial heads.

Since the geometrical dimensions of human heads (length, breadth, height, circumference), ears (pinna, ear canal, cavum chonchae) and shoulders have such a great influence on HRTFs, consequently each “geometrical dimensions clustered group”, which wants to accurately listen to artificial head recordings, would need its own artificial head.

By analogy with the above explanations, there is also a need for artificial heads for children. Investigation showed that HRTFs of children differ very much from HRTF of adults, which illustrates the necessity of the development of children-oriented artificial heads. By means of those artificial heads, adequate to certain ages and geometrical head dimensions respectively, e.g. the advanced development of hearing aids for children, is possible. [11]

Table III. - Ear-related dimension percentiles of males and females, published in Handbuch der Ergonomie 1975/1985 [4], ANSI S.3.36 – 1985 [5], IEC 959 [10], Burkhard & Sachs [7], Genuit [8]

Reference	Handbuch der Ergonomie male -1975, female - 1985			ANSI S.3.36 – 1986/ IEC 959	Burkhard & Sachs – (1975)	Genuit (1984)
	Percentile 5 (male/ female)	Percentile 50 (male/ female)	Percentile 95 (male/ female)			
Body Dimension in mm				Percentile 50	Average (male and female)	Average (male)
ear length	58/56	64/62	70/70	66	65.5	70
ear breadth	31/26	35/32	39/38	37	35.7	35
ear protrusion	17/13	20/16	24/19	23	21.6	-
concha length	-	-	-	28	26.3	30
concha breadth	-	-	-	23	18.0	21

Table IV. - Head-related dimension percentiles of males and females of different regions, published in International Data on Anthropometry (1989) [10]

Reference	International Data on Anthropometry [Percentile 50]					
	North America	Central Europe	North Africa	Japan	Australia	South East Asia
Male - Body Dimension in mm						
head breadth	155	155	145	155	155	145
head length	195	190	190	190	192	185
head circumference	575	575	560	555	565	565
Female - Body Dimension in mm						
head breadth	145	145	140	145	145	135
head length	180	180	185	180	180	175
head circumference	545	550	525	545	545	530

THE SIMPLIFICATION OF THE PINNA

A favored subject of discussion is the replication of the human pinna as the largely cartilaginous projecting portion of the external ear. The human pinna shows an enormous variance in geometry and shape, which make it almost impossible to detect an “average” pinna, as partially proposed by a few artificial head manufacturers. They suggest the replication of the human pinna with a complex lateral surface. The disadvantage is that the complex structure cannot be described in detail and thus, it is problematic insofar that no complete calibration of the system can be obtained. This means that HRTF of the respective artificial head must be permanently established anew by corresponding measurements and one cannot simply draw conclusions from the measured signals to the nature and characteristics of the acoustical phenomenon.

Thus, it is difficult to compare the recordings made with different pinnae with complex lateral surfaces resulting in inconsistent differences between artificial head systems.

With regard to the variance of the human pinna, an appropriate approach could be a pinna shape with simplified, mathematical describable geometry reflecting “all” acoustically-relevant features. By means of this approach, the actual impact on the HRTF caused by the specific pinna geometry can be estimated and calculated. This means that by the reduced outer geometry of the artificial head measuring system to the acoustically relevant geometry the acoustic behavior (reflection, diffraction, resonances) of the simplified body parts can be described mathematically. The artificial head measurement system can be calibrated in its parts as well as in its entirety.

Furthermore, because of the simplified geometry the pinna can be accurately produced by different manufacturers, which would decrease the differences caused by dissimilar pinnae.

An important criterion concerning the pinna simplification is that not only the resulting error is assessable, but also, that the error is within a “tolerable” range. Studies have shown [8] that the simplification of pinna geometry representing a mathematical describable geometry (e.g. elliptical disk) is suitable, since resulting HRTFs for the simplified pinna is within the range of the measuring accuracy and in the range of variations of HRTFs repetition measurements for one test subject. It is demonstrated that an artificial head measurement system with simplified mathematical describable geometry shows a comparable directivity pattern in comparison to an artificial head with “original” shaping. In [12], it is shown that between two artificial head systems – one with natural shaping, the other with simplified mathematical describable geometry – lies in the dimension which two subjects create with their individual differences regarding head and ear geometry. Figure 1-left depicts a comparison of two free-field HRTF for frontal incidence, the first based on the use of an artificial head closely matched with the original geometry of a test subject, whereas the second free-field HRTF was measured for an artificial head with simplified geometry (which means not only the simplification of the pinna, but also a head shape simplification). The figure shows the similarity of the two curves containing a comparable structure of the HRTFs. Figure 1-right additionally underlines the similarity of the curves in Figure 1-left, since the accuracy regarding the variation of the HRTF caused by repetition measurements are much larger than the deviations of the HRTFs between artificial heads with simplified geometry and human head detailed replicated geometry, which is also displayed in figure 2.

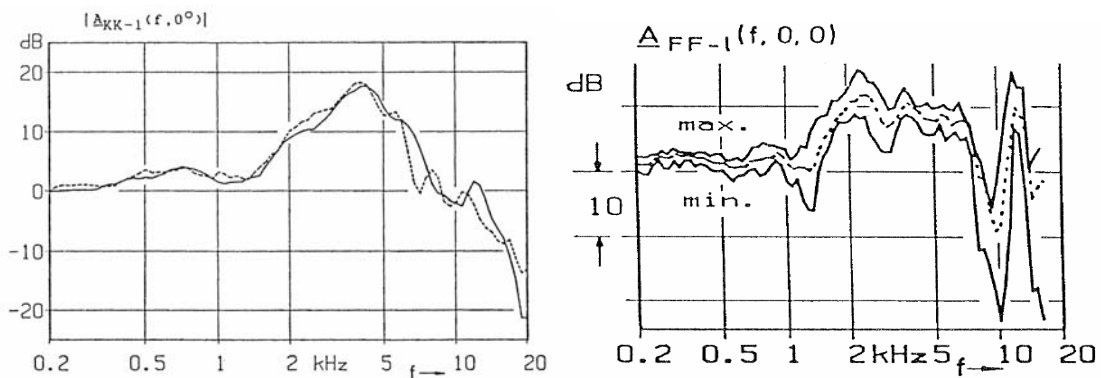


Figure 1. - Left: Comparisons of free-field transfer function $A_{KK-1}(f, 0^\circ)$ for frontal incidence, artificial head as a replica of a specific subject and - - artificial head with simplified geometry [8]; Right: Variation of free-field transfer functions $A_{FF-1}(f, 0, 0)$ for frontal incidence for one test subject after 6 repetition measurements (— range of dispersion, - - average) [8]

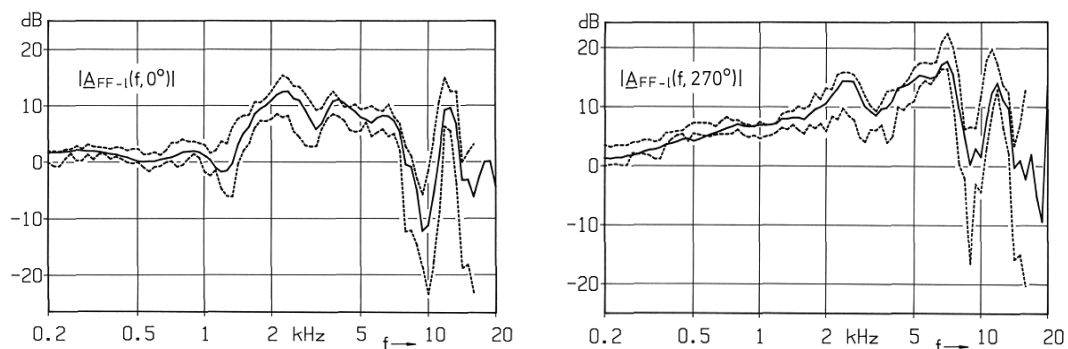


Figure 2. - Calculated HRTF of left human ear in comparison to the minima and maxima (...) given by six measurements at the same person [12]; left: frontal incidence, right: sound source directly facing the ear (here left ear)

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Due to dimensional, production (for example see table V) and measuring tolerances (see figure 4), the artificial head geometry as well as the respective binaural recordings differ - “legally

admissible” - from artificial head measurement system to artificial head measurement system. Caused by the tolerances - e.g. IEC report 959 defines only the magnitude of the free field head related transfer function for the main four angles of sound incidence laying down relatively large tolerances ranges - not only measurable but also perceivable differences between different measurement systems can be found.

Table V. – Head-related dimensions, published in ITU-T Recommendation P.58 (08/1996) [13]

Reference	ITU-T, P.58		
Dimension in mm	Nominal	Minimum	Maximum
head breadth	152	147	154
head length	191	190	205
head height (chin-to-vertex length)	224	216	225

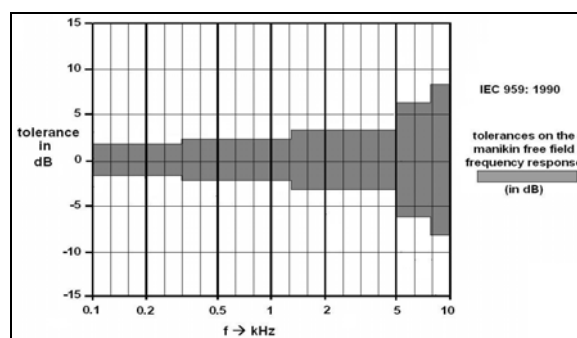


Figure 4. – Tolerances on the manikin free field frequency response in decibels, published in IEC 959 (1990-04) [10]

Correspondingly, several surveys clearly state the differences between different artificial head measurement systems and their recordings, among others, according to their different geometrical dimensions of head and ear. [8, 14, 15] In particular, the fact that almost small geometrical differences between artificial heads produce aurally-relevant differences resulting in a quite different sound impression (perceptible tonal color differences) without a great physically-measurable impact on the sound, illustrates the risk of using artificial head recordings for jury tests. Differences between individual systems cannot be simply equalized or corrected since the differences are direction-dependent. This potential biasing effect caused by the used artificial head and its geometry without identifying the deviating sound impression effect with conventional physical quantities is often not considered and interpreted.

The demand of the development of several artificial heads adequate to different listener types is consequent, but seems rather out of touch with reality. Either the appropriate clientele for listening to artificial head recordings is only small or numerous artificial heads have to be used and respective recordings have to be realized for a given listening group, which in turn would arise time and costs.

Fastl has stated that because of geometric differences of the dummy heads of different manufacturers, it is more or less impossible to get identical results when the same sounds are recorded by different dummy heads. An electronic equalization is easily done for one direction, e.g. frontal incidence, but next to impossible for all spatial directions. [15] Consequently, Fastl concluded that a standardized shell with standardized geometrical dimensions could be used for all dummy heads - binding for all manufacturers -, avoiding differences due to geometrical differences. In this context, the introduction of a mathematical describable geometry of the head appears to be favorable, enabling the production of “uniform” artificial heads and enhancing the comparability of recordings from different artificial heads. Quantitative directional tests for determining the directional pattern of an artificial head measuring system including a natural pinna in comparison with a measurement system with a simplified mathematically describable pinna show that there is no significant change between these two systems with respect to directional pattern in directivity auditory tests. [16]

The mathematical describable geometry of the head and ear will allow for the estimation and calculation of HRTF for specific conditions. Provided that the mistake caused by the deviations

of the artificial head geometrical dimensions compared with the respective listener is accepted, the advantage of a bias independent from the used artificial head or at least its geometry is achieved, which can be possibly reduced by electronic post-processing.

CONCLUSIONS

A recording of sound in the way as a human being would exactly hear the sound in the same position could only be achieved using an artificial head matched with the respective listeners. An "universal" artificial head can hardly cope with the demand to be accurate for all listener. Varying geometrical dimensions of human heads and ears lead to essential variations of the HRTFs. Thus, the search for an artificial head accurate to all listeners appears futile. Therefore, it has to be concluded that either each "anthropometric group" has its optimized and matched artificial head, which possibly means the need for a great variety of artificial heads, or an "universal" artificial head - at least for its geometry - is defined and standardized, which allow for the comparability of artificial head recordings, although realized with different artificial head measurement systems.

Fastl proposes the latter as "an obvious solution to the comparability problem of different dummy heads [...]". [15] In this case the artificial head geometry must be matched with the "typical" human head, which requires further work in the field of anthropometry in order to define the geometry of the "average" subject. In this context, it has to be mentioned that some theoretical considerations regarding human binaural processing should guide the search for the adequate artificial head geometry. For example, it is expected that slightly bigger heads produce larger interaural differences and spatial cues, which in turn could lead to improved source localization ability. Furthermore, in contrast to closely replicated human body parts (head, pinna), a simplified geometry of the pinna enables the mathematical estimation and a system-theoretical description of the head related transfer function, which, in dependency on the significant geometrical data of a test person, leads to similar results as the measured transfer function. Such potential effects and considerations have to be reflected regarding the determination of representative artificial head geometry.

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