# The Oldenburg Hearing Device (OlHeaD) HRTF Database

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# 1 Outline

This document describes the Oldenburg database of Head-related Transfer Functions (HRTF) in hearing devices (OlHeaD-HRTF database). It can be downloaded at medi.uni-oldenburg.de/hearingdevicehrtfs/. HRTFs to the eardrum and 13 microphone locations contained in 6 hearing device styles were recorded for 91 incidence directions in the ears of 16 human subjects and 3 dummy heads. The measurements and specific measurement technologies are described in detail in [1–3]. Examinations of external ear acoustics related to hearing devices based on the database are made in [1, 4]. When you use this database, please cite

> F. Denk, S.M.A. Ernst, S.D. Ewert and B. Kollmeier (2018) Adapting hearing devices to the individual ear acoustics: Database and target response correction functions for various device styles. *Trends in Hearing, vol 22, p. 1-19. DOI: 10.1177/2331216518779313*



# 2 Database

## 2.1 HRTFs

The HRTFs are provided as impulse responses (Head-Related Impulse Responses HRIRs) with a sampling rate of 48 kHz and a length of 256 samples, including a common delay of 48 samples and hann-ramps of 16 samples applied at the beginning and end. The number of rejected negative-time samples is stored for each set to provide information of the delay between microphone locations; different microphones in one hearing device have not been shifted against each other.
The responses cover a frequency range up to 20 kHz; below 60 Hz an extrapolation to a flat response was applied. They were measured using overlapping exponential sweeps with an individual length of 4.1 seconds [5]. Transfer functions of the microphones and loudspeakers were equalized by spectral deconvolution; acoustic reflections were removed by frequency-dependent truncation [1, 3].

## 2.2 In-Ear Recording Locations

All recording devices in the ear of an exemplary subject are show in Fig. 1. In all recording locations except the eardrum, wide frequency range miniature electret microphones were utilized (*Knowles FG-23329* or *GA-38*). The bold key names indicate the names under which the HRTFs are stored.

**ED** Eardrum. Measurements were conducted with an audiological probe tube microphone (*Primus Probe*), which was inserted up to contact with the eardrum and then pulled back by a minimal amount.

**ECEbl** Blocked Ear Canal Entrance. Miniature microphones were inserted into anthropometric earplugs in 3 sizes [6] shown in the according inset in Fig. 1. The earplugs provide a deep and reproducible fit.

**InsertHP** Microphone on a small insert headphone (*Sennheiser CX200*). A minimal portion of soft material was attached to the surface and the microphone flush inserted into a hole. Depending on the subject's ear size, the headphone fills approx. half of the cavum concha. The microphone is located near the concha bottom pointing backwards (see also Fig. 1). A standard flange eartip was selected for the individual subjects from 3 sizes (sizes provided for the individual subjects).

**TrEPind** Multi-microphone "transparent" earpiece as described in [**denk˙individualised˙2017**]. It consists of an individual silicone earmould containing 3 microphones and 2 drivers. One microphone (**TrEPind_Concha**) is located in the rear part of the cavum concha, whereas the other transducers are contained in a pipe ("core") inserted in a bore through to the ear canal. There, one microphone is located at the outside near the ear canal entrance (**TrEPind_Entr**), and one inside in the ear canal (**TrEPind_InEar**). Entrance and Concha microphone are approximately 6-11 mm apart from each other (distances are provided for the individual subjects) in a preferably horizontal orientation.

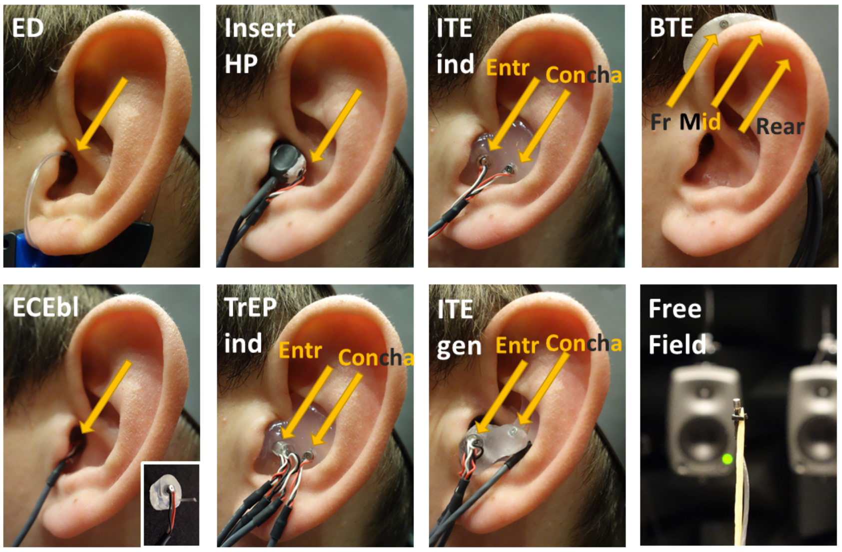


Figure 1: Photograph of all HRTF recording devices in the ear of a subject. Arrows mark the microphone position and name. The bottom right shows image a free-field measurement of a miniature microphone.

**ITEind** Individual In-the-Ear (ITE) hearing device. In the same individual earmould as with the TrEPind, one microphone was placed at the ear canal entrance flush with the earmould (**ITEind_Entr**), and another microphone in the concha (**ITEind_Concha**). The distance between the microphones is 6-11 mm, and provided for every subject.

**ITEgen** Generic ITE device. It contains the same transducer configuration as the TrEPind, but placed in a generic earplug. A custom adaptor piece was constructed, which contains all microphones (**ITEgen_InEar**, **ITEgen_Entr**, **ITEgen_Concha**) and fits into a generic headphone earplug with a concha hook (*Bose StayHear+*©). The device sticks further out of the ear than the individual earmould, and the cavum concha is filled less uniformly. The distance between Entr and Concha microphone is 11 mm. The device can be considered a larger insert headphone with integrated microphones.

**BTE** A 3-microphone behind-the-ear hearing aid form equipped with miniature microphones. According to their positions, the individual microphones are referred to as front mic (**BTE_fr**), middle mic (**BTE_mid**), and rear mic (**BTE_rear**). The distance between microphones is approx. 7.6 mm, the geometry is the same as in [7]. Note: In Fig. 1, mid and rear microphones are covered by the pinna.

## 2.3 Recording Room and Spatial Sampling

The measurements were conducted in the Virtual Reality Lab of Oldenburg University depicted in Fig. 2, which is an anechoic chamber featuring a multichannel 3D loudspeaker setup with the spatial layout shown in Fig. 3. Each incidence direction was measured with an individual loudspeaker (Genelec 8030b / 8020b) mounted between 2.5 and 3 m from an acoustic centre with a vertical orientation (effects of varying distance compensated).
48 loudspeakers are located in the horizontal plane leading to a uniform resolution of 7.5°. The rest of the sphere is sampled with a spacing of 30°, but with extra speakers in the median plane and another (approximated) cone of confusion at 30° lateral angle in the right hemisphere.

## 2.4 Subjects and Dummy Heads

16 subjects (10 male, 6 female) between 20 and 36 years of age participated in the study. They were a-priori grouped to expert and naive listeners (internal names: VP_E#, VP_N#). Their sex and sizes of generic earplugs are provided to give rough information about their ear size.

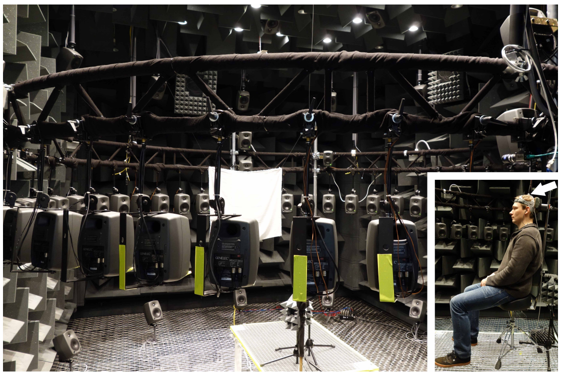

Figure 2: Photograph of the recording room with measurement setup. Inset: subject in the process of performing the measurement, arrow marking the headtracker sensor.

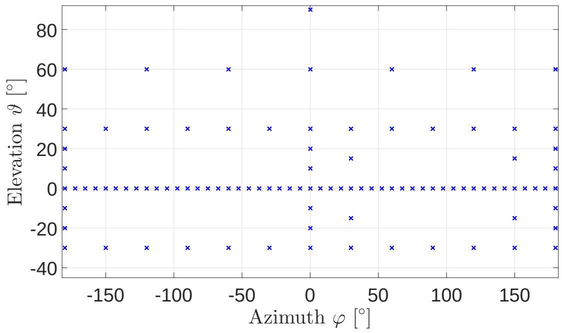


Figure 3: Spatial sampling grid of the HRTF datase in navigational coordinates. Positive azimuth values denote the right-hand hemisphere, positive elevations incidence directions above the horizontal plane.

3 dummy heads are included in the database: A Brüel&Kjær HATS 4128C (internal name: BuK), a G.R.A.S. KEMAR (internal name: KEMAR), and a custom dummy head with adjustable ear canals [8] (internal name: DADEC). More information on the dummy heads is provided separately.

### 2.5 Free- and Diffuse Field Transfer Functions

For convenience, the amplitude transfer functions for the free-field (i.e., frontal incidence) and an approximated diffuse field are provided as shown in [1, Fig. 4]. They have been smoothed to auditory resolution and are stored as the corresponding minimum-phase impulse response. The arithmetic average of all human subjects is supplied as well (subject name 'Avg', averaging done on the dB amplitudes).

### 2.6 Headphone Transfer Functions

The HRTFs are supplemented by corresponding Headphone Impulse Responses (HpIR) for the Sennheiser HD650 (produced: 2015). They were not measured for the BTE microphones, and for the Eardrum only in the dummy heads. The microphone response was equalized, the level is adjusted relative to 1 kHz.

### 2.7 Head Positioning

The subjects were positioned in the acoustic centre of the loudspeaker array. During the experiment, their head position and orientation relative to a starting position was monitored and interactively controlled via a headtracker, resulting in a negligible source shift of less than 0.5° (median: 0.2°) [2]. The head position and orientation during measurement of each incidence direction is provided with the dataset.

### 2.8 Data Format and Handling

The data is provided in a custom `.mat` format for use in Matlab©/ Octave defined in section 4, as well as in the dedicated SOFA format [9]. All data is stored as binaural files. For all hearing devices containing more than one microphone in each ear, an additional multi-channel file is provided.
Files are named as follows: <SubjectName>-<LocationName>.<type>
The names of the subjects and microphone locations are listed in the cell files `c_vpnames.mat` and `c_locnames.mat`, respectively. HRIRs, Free- and Diffuse Field Transfer functions and HpIRs are stored in separate folders for `.mat` and SOFA files.
The content and structure of the `.mat` files is listed in section 4. The SOFA files correspond to convention 1.0, as specified by AES69-2015 [10].
HRIRs for a specific subject, microphone location and incident direction can be easily loaded from Malab/Octave using the supplementary function `loadHRIR()`. Equivalently, Free- and Diffuse Field Transfer Functions (minimum-phase IR) can be loaded using the supplementary function `loadFF_DF_IR()`

## 3 Acknowledgement

This work was funded by the DFG through Research Unit 1732 *Individualized Hearing Acoustics* and the Cluster of Excellence *Hearing4all*. We acknowledge Lena Haverkamp for placing the probe tube microphones, Felix Grossmann for assistance in installing the setup and Hendrik Kayser and Giso Grimm for helpful discussions. We thank Fabian Brinkmann from TU Berlin for kindly providing the 3D models of the earplugs for the blocked ear canal measurements.

## References

[1] Florian Denk et al. "Adapting Hearing Devices to the Individual Ear Acoustics: Database and Target Response Correction Functions for Various Device Styles". In: *Trends in Hearing* 22 (Jan. 1, 2018), p. 2331216518779313.

[2] Florian Denk et al. "Controlling the Head Position during individual HRTF Measurements and its Effect on Accuracy". In: *Fortschritte der Akustik - DAGA*. Kiel, Mar. 17, 2017.

[3] Florian Denk, Birger Kollmeier, and Stephan Ewert. "Removing reflections in semianechoic impulse responses by frequency-dependent truncation". In: *Journal of the Audio Engineering Society* 66.3 (Mar. 19, 2018), pp. 146–153.

[4] Florian Denk, Stephan D. Ewert, and Birger Kollmeier. "Spectral directional cues captured by hearing device microphones in individual human ears". In: *The Journal of the Acoustical Society of America* 144.4 (Oct. 2018), pp. 2072–2087.

[5] Piotr Majdak, Peter Balazs, and Bernhard Laback. "Multiple exponential sweep method for fast measurement of head-related transfer functions". In: *Journal of the Audio Engineering Society* 55.7 (2007), pp. 623–637.

[6] Alexander Lindau and Fabian Brinkmann. "Perceptual Evaluation of Headphone Compensation in Binaural Synthesis Based on Non-Individual Recordings". In: *Journal of the Audio Engineering Society* 60.1 (Mar. 20, 2012), pp. 54–62.

[7] Hendrik Kayser et al. "Database of Multichannel In-Ear and Behind-the-Ear Head-Related and Binaural Room Impulse Responses". In: *EURASIP Journal on Advances in Signal Processing* 2009.1 (2009), p. 298605.

[8] Marko Hiipakka, Miikka Tikander, and Matti Karjalainen. "Modeling the external ear acoustics for insert headphone usage". In: *Journal of the Audio Engineering Society* 58.4 (2010), pp. 269–281.

[9] Piotr Majdak et al. "Spatially oriented format for acoustics: A data exchange format representing head-related transfer functions". In: *Audio Engineering Society Convention 134*. Audio Engineering Society, 2013.

[10] AES. *AES69-2015 standard for file exchange - Spatial acoustic data file format*. 2015.

# 4 Structure of .mat files

## HRIR data containers

Name format: HRIRs_MAT/<s_vpname>-<s_locname>.mat

Square brackets indicate general values.

c_channel_names : Cell containing description of channels as strings, usually left and right.
c_data_dims : Description of dimensions in M_data:
    Dim 1: Data
    Dim 2: Source Direction
    Dim 3: Channel, as described in c_channel_names (usually 1: left, 2: right)
c_legend_headpos : Contents of the rows in M_headpos, describing the head coordinate system
    X : Front(positive) / back, in cm
    Y : Left (negative) / right, in cm
    Z : Up (positive) / down, in cm
    Yaw : Rotation around Z-Axis, positive towards right, in degrees
    Pitch: Rotation around Y-Axis, positive towards top, in degrees
    Roll: Rotation around X-Axis, positive towards right, in degrees
c_mic_names : Internal names of utilized microphones for each channel.
c_mic_types : Types of utilized microphones for each channel.
M_data : Impulse response data
M_directions : Source incident directions, given in navigational coordinates and degrees. 1st row: Azimuth, 2nd row: elevation
M_headpos Head position and orientation (given in cm and euler angles in degrees) of the subject relative to the resting position during measurement of each incidence direction. Each row contains the data according to c_legend_headpos.
n_samples_rejected : Number of samples prior to the peak that were cut away to get a common delay of 48 samples in the current HRTF set. Provided to conserve timing information between recording locations.
s_locname : string indicating the name of the recording location in ear
s_subj_info : string containing information about the subject or dummy head
s_type : string indicating the data type [HRIR]
s_vpname : string indicating the name of the subject
srate : Sampling rate in Hz [48000]
T_shft_common : Common delay of IR in seconds [0.001]

## Free / Diffuse Field Transfer Function data containers

Name format:
FreeFieldIRs_MAT/<s_vpname>-<s_locname>.mat, DiffFieldIRs_MAT/<s_vpname>-<s_locname>.mat

As the HRIR containers, but with the following entries missing:
c_legend_headpos,M_headpos, n_samples_rejected, T_shift_common.

For the average curves (s_vpname = 'Avg'), the entries c_mic_names, c_mic_types are also excluded. In The Diffuse Field Transfer function containers, the field M_directions indicates the incidence directions used for averaging to approximate diffuse-field incidence [1].

## HpIR data containers

Name format: HpIRs_MAT/<s_vpname>-<s_locname>.mat.

Square brackets indicate general values.

c_channel_names : Cell containing description of channels as strings, usually left and right.
c_data_dims : Description of dimensions in M_data:
    Dim 1: Data
    Dim 2: Channel, as described in c_channel_names (usually 1: left, 2: right)
c_mic_names : Internal names of utilized microphones for each channel.
c_mic_types : Types of utilized microphones for each channel.
M_data : Impulse response data
s_locname : string indicating the name of the corresponding HRTF set
s_subj_info : string containing information about the subject or dummy head
s_type : string indicating the data type [HpIR]
s_vpname : string indicating the name of the subject
srate : Sampling rate in Hz [48000]
T_shft_common : Common delay of IR in seconds [0.010]