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Measuring room acoustic parameters using a head and torso simulator instead of an omnidirectional microphone

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ABSTRACT

One of the parameters for an objective measurement of the acoustical spaciousness in a room is the IACC. According to ISO 3382-1 this parameter must be measured using a head and torso simulator (HATS). According to the same standard, all other room acoustical parameters (related to loudness, reverberation, clarity and speech intelligibility) must be measured using an omni-directional microphone. The feasibility was investigated of using a HATS to measure, in addition to the IACC, other parameters given in ISO 3382-1. Room acoustical parameters measured with a HATS were compared with the same parameters measured with an omnidirectional microphone. Here the HATS was rotated around its vertical axis in steps of 10 degrees, where at each step a measurement was performed. The main result is a set of polar diagrams in which all measured parameters display a clear directivity. Angle-independent single-number quantities obtained through averaging are partially comparable to those from omnidirectional measurements.

1. INTRODUCTION

ISO 3382-1[1] defines several objective parameters used to describe the acoustics of a hall. These parameters can be separated in 2 groups. The first group consists of parameters that can be measured with relative ease using an omnidirectional microphone, such as the Strength (G), the Early Decay Time (EDT), the Reverberation Time (T_{20} en T_{30}), the Clarity (C_{80}) and the Definition (D_{50}). The second group contains the dual-channel parameters such as the Early Late

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Lateral Energy (LF and LFC), the Late Lateral Energy (LG) and the Inter Aural Cross Correlation (IACC). These parameters cannot be measured with a single omnidirectional microphone, but are directional parameters derived from two impulse responses. The IACC in particular is a parameter requiring a special microphone configuration. Unlike other dual-channel parameters, the IACC does not contain an omnidirectional component. The admittedly omnidirectional microphones are mounted in an artificial head with artificial ears, a so-called HATS[2] (head and torso simulator), resulting in a directional sensitivity much like human ears. This is why in ISO-3382-1 the measurement of omnidirectional parameters using a HATS is not mentioned. But what are the differences between measurements with an omnidirectional microphone and with a HATS? Is it necessary to measure with both? What about the directivity of the HATS for single-channel ISO parameters? What are the parameter differences between the ears? Can the omnidirectional values be arrived at through averaging of HATS measurements? The 'omni' and HATS values for four room acoustical parameters were compared. In a concert hall, the G[3], EDT[4], T_{30}[1,5] en C_{80}[6] were measured at two positions, both with an omnidirectional microphone and a HATS. A description and some results of this explorative investigation are given in this paper.

2. MEASUREMENTS

A. Measurement conditions

To evaluate the difference between an omnidirectional microphone and a HATS on the measured room acoustic parameters, impulse response measurements were performed in the large concert hall of "Muziekcentrum Eindhoven" with a volume of approx. 14,400 m^3, an unoccupied stage floor and $T_{empty} \approx 2$ s. Figure 1 gives an impression of the hall and a schematic floorplan with the source position S as indicated, placed on the major axis of the hall, and the microphone positions R1 and R2, where R1 is placed at approx. 5 m from the source, equal to the critical distance and R2 is placed at approx. 18 m (diffuse field). More specifications of the concert hall are presented in table 1, using the omnidirectional microphone measurements of this investigation.

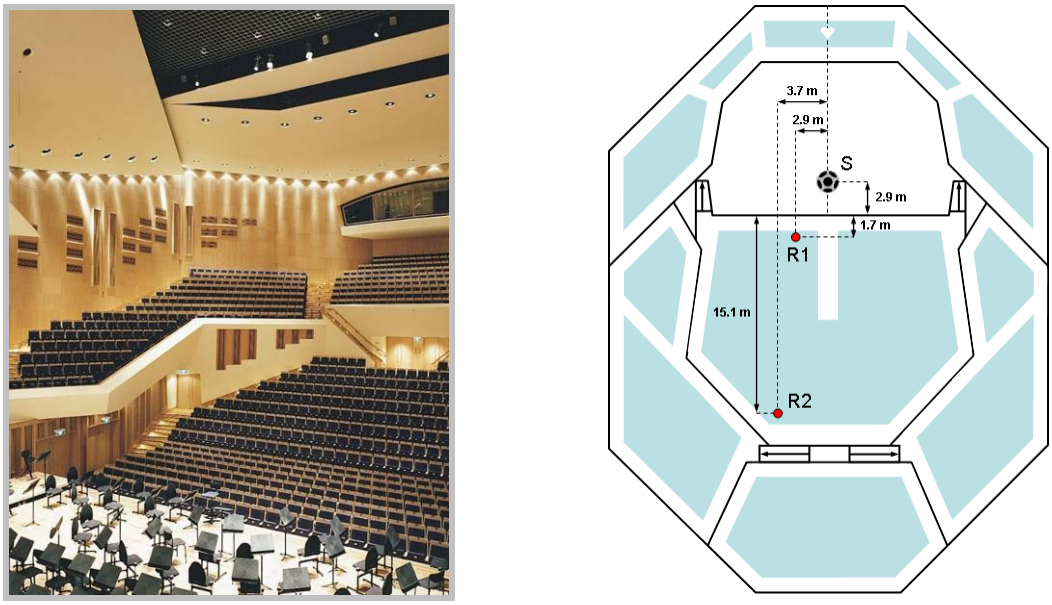


Figure 1: Impression of the "Muziekcentrum Eindhoven" and floorplan with source and receiver positions

Table 1: Acoustic parameter values measured on position **R1**, according to ISO 3382-1

Room acoustic parameter	Octave band [Hz]								
	125	250	500	1k	2k	4k	**Low**	**Mid**	**High**
Strength G [dB]	8.0	6.0	6.9	6.2	6.9	7.4	7.0	6.5	7.2
Early Decay Time EDT [s]	2.3	2.1	1.9	1.9	1.8	1.4	2.2	1.9	1.6
Reverberation Time T_{30} [s]	2.3	2.1	2.0	2.0	2.0	1.7	2.2	2.0	1.9
Clarity C_{80} [dB]	2.5	2.6	3.3	3.2	4.0	6.1	2.6	3.2	5.0

Table 2: Acoustic parameter values measured on position **R2**, according to ISO 3382-1

Room acoustic parameter	Octave band [Hz]								
	125	250	500	1k	2k	4k	**Low**	**Mid**	**High**
Strength G [dB]	5.9	3.5	4.4	4.3	2.9	2.5	4.7	4.3	2.7
Early Decay Time EDT [s]	1.8	1.9	1.5	1.7	1.9	1.5	1.8	1.6	1.7
Reverberation Time T_{30} [s]	2.3	2.1	2.1	2.0	2.0	1.8	2.2	2.0	1.9
Clarity C_{80} [dB]	-2.4	-3.9	-0.1	0.2	-1.0	0.7	-3.1	0.1	-0.2

Low: Average over 125 and 250 Hz octave band, Mid: average over 500 and 1000 Hz octave band, High: average over 2000 and 4000 Hz octave band

B. Measurement definitions

The *source direction* is defined in terms of the 'line of sight' of the HATS to the source, where the direction is specified as the angle between the line of sight and the major axis of the hall. For R1 this angle ≈ 32° while for R2 the angle ≈ 12°. The *stage viewing angle* is the angle between the line of sight of the HATS when pointed into the direction of the leftmost side of the stage, and the the line of sight when pointed to the rightmost side of the stage. For R1 this angle ≈ 156° while for R2 the angle ≈ 60°. See figure 2 for clarification.

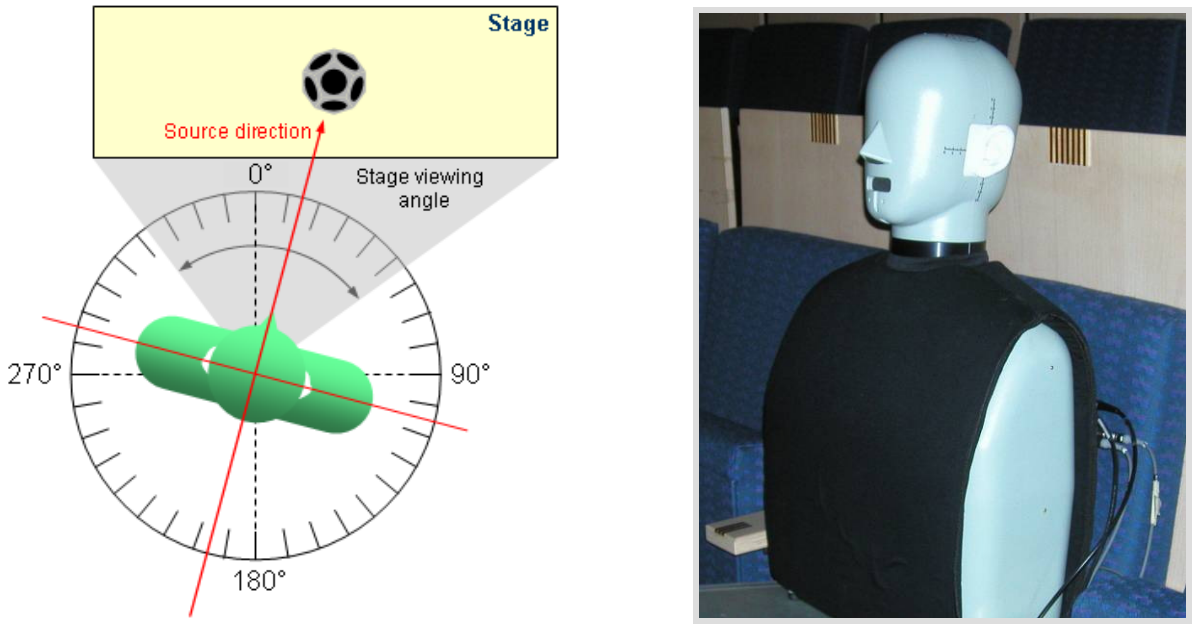


Figure 2: During the measurements the HATS from Bruel & Kjær turned in steps of 10°

C. Measurement equipment

The measurement equipment consisted of the following components:

- *microphone 1:* omnidirectional (Rion – NL 21);
- *microphone 2:* head and torso simulator HATS[2] (B&K - Type 4128C);
- *power amplifier:* (Acoustics Engineering - Amphion);
- *sound source:* omnidirectional (B&K - Type 4292);
- *sound device:* USB audio device (Acoustics Engineering - Triton);
- *software:* DIRAC (B&K/Acoustics Engineering - Type 7841)

Using a special construction the HATS could rotate 360° around its vertical axis. After removal of the HATS, the omnidirectional microphone was placed on a position centered between the ears of the HATS. The decay range (INR[7]) for all impulse responses measured with this setup had an average of 60 dB for all frequency bands, with a minimum exceeding 45 dB.

3. RESULTS

For a single source position (S) and two microphone positions (R1 and R2) the differences between 'omnidirectional parameter values' and the same parameters measured with a HATS were investigated. Polar plots containing the measurement results can be found in tables 4 and 5, where 3 frequency ranges are distinguished: 'Low' as average over the 125 Hz and 250 Hz octave bands, 'Mid' as average over the octave bands 500 Hz and 1 kHz, and 'High' being the average over the 2 kHz and 4 kHz octave band values.

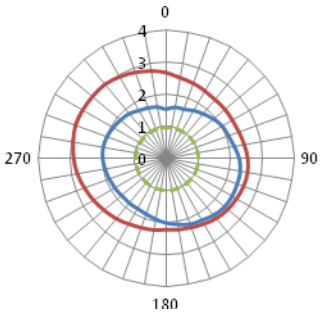
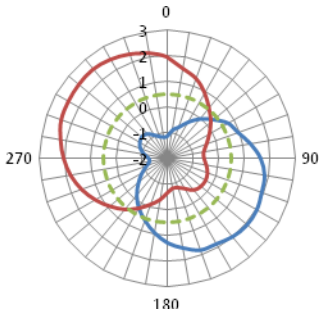
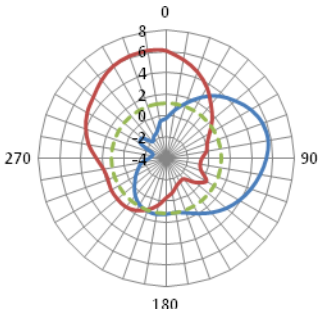
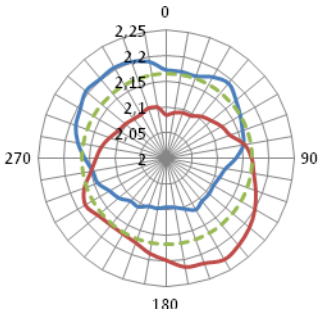
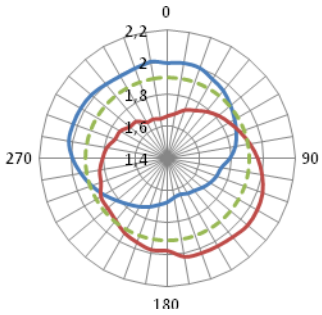
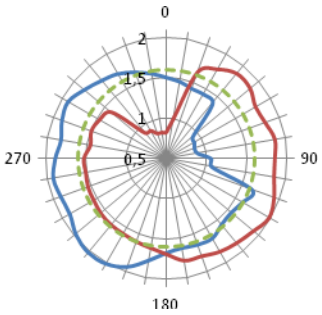
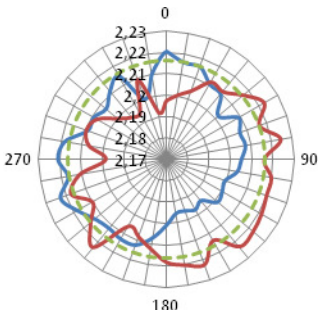
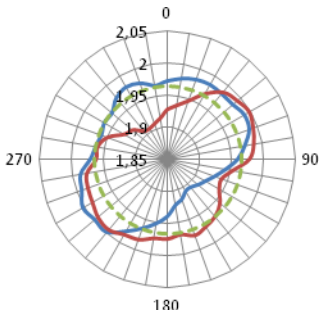
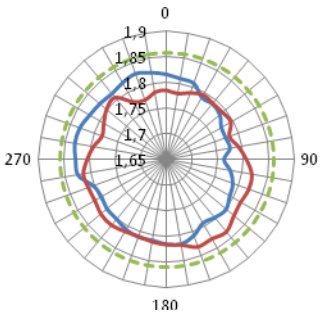
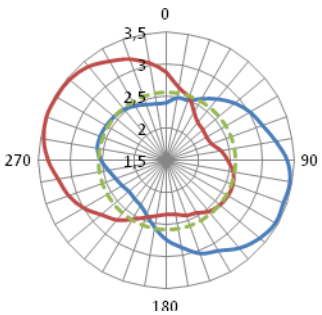
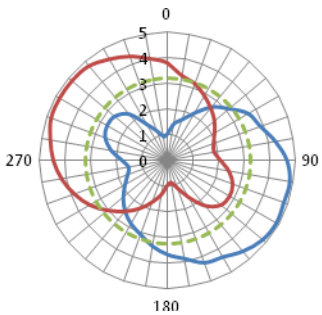
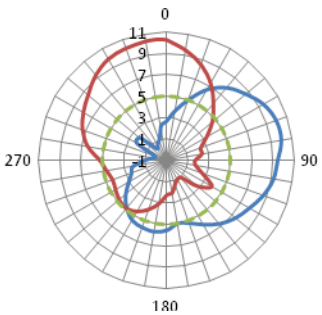
For the room acoustical parameters Strength (G), Early Decay Time (EDT), Reverberation Time T_{20} en Clarity (C_{80}), described in ISO-3382-1, the polar plots are given for both the omnidirectional microphone and the HATS at the exact same listener position. Here the HATS was rotated around its vertical axis in steps of 10 degrees, where at each step a measurement was performed. In addition to the polar plots, average numeric values were calculated and presented in tables 6 through 9. Tables 6 and 7 contain the results for receiver position R1; tables 8 and 9 for position R2. Tables 6 and 8 list the differences between the omnidirectional microphone and the HATS. Tables 7 and 9 contain the absolute maximum differences between both ears of the HATS. Results are listed averaged over a full rotation of the HATS over 360°, averaged over a partial rotation over the stage viewing angle, and for the fixed source direction. For all tables, results higher than the JND (Just Noticeable Difference) are marked grey.

Notable in the polar plots, both for the position close to the source (table 4) and for the position at a larger distance (table 5), is the clear directivity of the hall for all parameters that were investigated. Although this also holds for the reverberation time T_{30}, the directivity of this parameter will not be perceivable for the human ear. Averaging over 360° for both receiver positions results in a C_{80} value that differs less than the JND from the omnidirectional measurement. Also notable in tables 7 and 9 is the difference between both ears. Only for the measured reverberation time the maximum difference is below JND for all angles. In particular the Strength and the Clarity show differences of 4 times the JND at position R2 up to 8 times the JND at position R1, even when just considering the *stage viewing angle*. Table 3 list the JND values for the used parameters[1].

Table 3: JND values

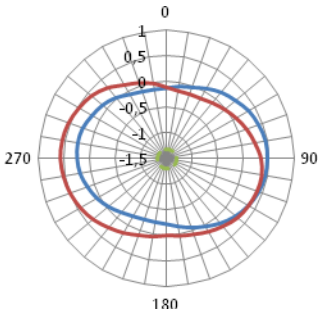
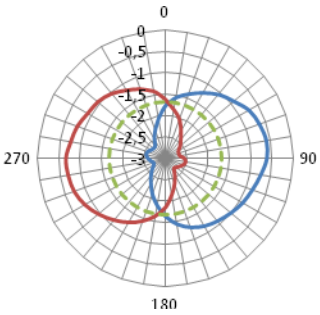
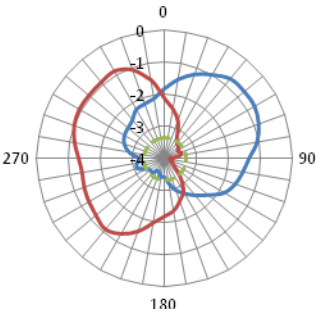
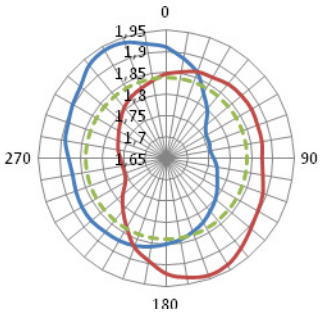
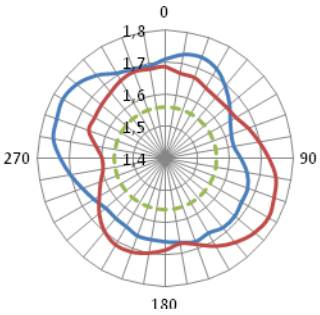
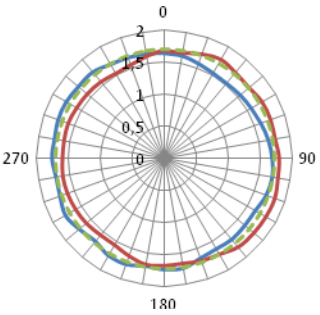
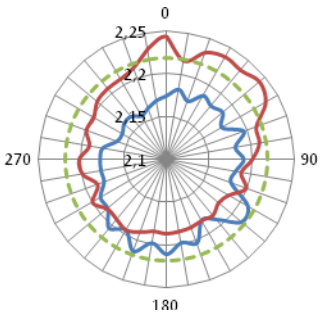
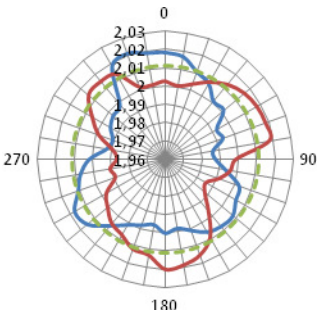
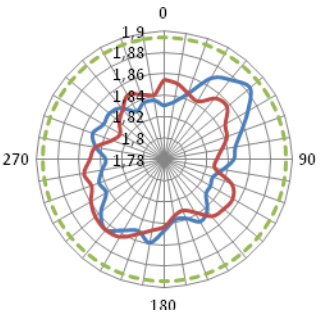
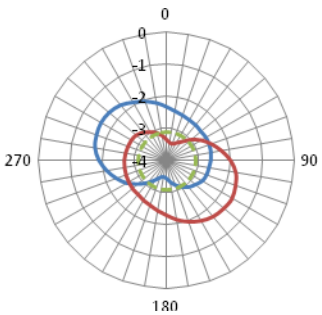
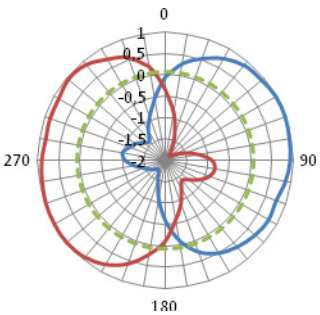
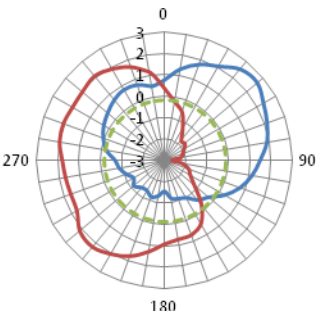
G	EDT	T_{30}	C_{80}
1 dB	5 %	10 %	1 dB

Table 4: Parameter value differences between omnidirectional microphone and HATS for receiver position **R1**, with sound-receiver-distance of 5 m and source viewing angle of 32°

	Low	Mid	High
G [dB]			
EDT [s]			
T_{30} [s]			
C_{80} [dB]			

omni — right ear — left ear

Table 5: Parameter value differences between omnidirectional microphone and HATS for receiver position **R2**, with sound-receiver-distance of 18 m and source viewing angle of 12°

	Low	Mid	High
G [dB]			
EDT [s]			
T_{30} [s]			
C_{80} [dB]			

omni right ear left ear

Table 6: Parameter value differences between omnidirectional microphone and HATS for Receiver position **R1**, with sound-receiver-distance of 5 m and source viewing angle of 32°

Room acoustic parameter	Average over 360°								
	Left ear			Right ear			Average (L,R)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	0.97	-0.30	0.06	1.60	0.25	0.85	1.28	-0.03	0.46
Early Decay Time EDT [s]	-0.02	-0.05	-0.01	-0.02	-0.05	-0.03	-0.02	-0.05	-0.02
Reverberation time T_{30}[s]	-0.01	-0.01	-0.06	-0.01	-0.01	-0.06	-0.01	-0.01	-0.06
Clarity C_{80} [dB]	0.18	-0.29	-0.05	0.19	-0.24	0.08	0.18	-0.26	0.02
	Average over stage viewing angle								
	Left ear			Right ear			Average (L,R)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	0.86	-0.93	-0.22	1.70	0.94	2.62	1.28	0,01	1.20
Early Decay Time EDT [s]	0.01	0.06	-0.13	-0.06	-0.16	-0.20	-0.02	-0.05	-0.17
Reverberation time T_{30} [s]	-0.01	0.00	-0.05	-0.01	-0.02	-0.07	-0.01	-0.01	-0.06
Clarity C_{80} [dB]	0.10	-0.87	-0.69	0.17	0.29	1.81	0.14	-0.29	0.56
	Sound source direction								
	Left ear			Right ear			Average (L,R)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	0.80	-0.70	1.99	1.41	0.25	1.85	1.10	-0.23	1.92
Early Decay Time EDT [s]	0.02	0.04	-0.19	-0.07	0.02	0.16	-0.03	0.03	-0.02
Reverberation time T_{30} [s]	-0.01	0.01	-0.07	-0.01	0.06	0.12	-0.01	0.04	0.02
Clarity C_{80} [dB]	0.12	-0.82	2.22	-0.25	-0.45	1.49	-0.06	-0.64	1.85

Table 7: Maximum parameter value differences between the Left and the Right ear of a HATS for receiver position **R1**, with sound-receiver-distance of 5 m and source viewing angle of 32°

Room acoustic parameter	$\lvert$ Left ear – Right ear $\rvert_{max}$								
	360°			Stage viewing angle			Source direction		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	1.19	3.42	7.53	1.19	3.42	7.53	0.68	1.32	1.18
Early Decay Time EDT [s]	0.12	0.38	0.98	0.11	0.36	0.98	0.09	0.22	0.49
Reverberation time T_{30} [s]	0.03	0.07	0.05	0.02	0.07	0.05	0.00	0.02	0.01
Clarity C_{80} [dB]	0.92	3.11	9.14	0.90	3.11	9.14	0.49	0.79	2.04

Low: 125 and 250 Hz octave band Mid: 500 and 1000 Hz octave band High: 2000 and 4000 Hz octave band

Table 8: Parameter value differences between omnidirectional microphone and HATS for Receiver position **R2**, with sound-receiver-distance of 18 m and source viewing angle of 12°

Room acoustic parameter	Average over 360°								
	Left ear			Right ear			Average (L,R)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	1.40	-0.04	1.03	1.51	-0.06	1.10	1.46	-0.05	1.07
Early Decay Time EDT [s]	0.01	0.12	-0.03	0.01	0.12	-0.04	0.01	0.12	-0.03
Reverberation time T_{30}[s]	-0.04	-0.01	-0.04	-0.02	-0.01	-0.04	-0.03	-0.01	-0.04
Clarity C_{80} [dB]	0.54	-0.37	-0.38	0.53	-0.31	0.50	0.54	-0.34	0.44
	Average over stage viewing angle								
	Left ear			Right ear			Average (L,R)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	1.30	1.03	2.72	1.27	0.93	2.37	1.29	0.98	2.54
Early Decay Time EDT [s]	0.04	0.15	-0.10	0.01	0.11	-0.03	0.02	0.13	-0.07
Reverberation time T_{30} [s]	-0.04	0.00	-0.04	0.01	-0.01	-0.04	-0.02	0.00	-0.04
Clarity C_{80} [dB]	0.71	0.07	1.54	-0.20	-0.83	0.02	0.25	-0.38	0.78
	Sound source direction								
	Left ear			Right ear			Average (L,R)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	1.44	0.55	2.45	1.19	-0.67	0.00	1.32	-0.06	1.23
Early Decay Time EDT [s]	0.03	0.29	0.03	0.02	0.17	-0.03	0.03	0.23	0.00
Reverberation time T_{30} [s]	-0.04	0.06	0.12	0.00	0.07	0.11	-0.02	0.06	0.12
Clarity C_{80} [dB]	0.60	-1.87	0.57	-0.34	-2.93	-0.95	0.13	-2.40	-0.19

Table 9 : Maximum parameter value differences between the Left and the Right ear of a HATS for receiver position **R2**, with sound-receiver-distance of 18 m and source viewing angle of 12°

Room acoustic parameter	$\lvert$ Left ear – Right ear $\rvert_{max}$								
	360°			Stage viewing angle			Source direction		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Strength G [dB]	0.39	2.04	2.79	0.28	1.39	2.63	0.15	0.64	1.58
Early Decay Time EDT [s]	0.12	0.14	0.20	0.11	0.07	0.23	0.03	0.07	0.15
Reverberation time T_{30} [s]	0.07	0.02	0.03	0.07	0.02	0.03	0.06	0.02	0.02
Clarity C_{80} [dB]	1.18	2.75	4.42	1.03	2.73	4.35	0.98	1.87	2.41

Low: 125 and 250 Hz octave band Mid: 500 and 1000 Hz octave band High: 2000 and 4000 Hz octave band

4. CONCLUSIONS

Starting from a single source position and a large number of measurements at two receiver positions with an omnidirectional microphone and a HATS in a concert hall, the following can be concluded:

- Measurements with a HATS show a clear directivity of the hall for the Strength G, the Early Decay Time EDT, the Reverberation Time T_{30} and the Clarity C_{80}, for all measured frequency bands.
- In all cases, the Reverberation Time T_{30} measured with a HATS deviates less than 3.5 % (< 0.35 JND) from the value measured with an omnidirectional microphone. The other parameters in many cases result in a deviation exceeding the JND.
- Listening under any direction to the stage (with a single source position) can result in differences in the Strength G and the Clarity C_{80} of more than 2 dB within the stage viewing angle.
- For the Strength G and the Clarity C_{80} differences between the ears can reach up to 8 dB, depending on listening direction and frequency.
- For most omnidirectional measured acoustical parameters, it seems that it is not possible to use the HATS instead of the omnidirectional microphone except for the T_{30}.

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