Audiometric Properties of Three Circumaural Earphones

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Introduction

We compared the performance of three earphones usable for audiometry. The Sennhesier HDA 200 earphone has been used in audiometry for many years. Reference equivalent threshold sound pressure levels (RETSPLs) for that earphone are included in American and international audiometer standards (ANSI S3.6-2010 and ISO 389-8-2004). A new earphone, the HDA 300, has been developed by Sennheiser as a replacement for the HDA 200. The HD 280 Pro is a consumer product that may provide a low-cost alternative to the HDA 300. In addition to determining RETSPLs we also compared input impedances, sensitivities, ambient noise attenuation, occlusion effect, and total harmonic distortion (THD). Ambient noise attenuation results were used to determine the maximum permissible ambient noise levels (MPANLs) for audiometric testing (ANSI S3.1-1999). The occlusion effect is relevant for audiometric testing when masking is presented to the non-test ear by an occluding earphone. This is especially important for bone-conduction testing with automated pure-tone audiometry, because the earphones used for air-conduction testing must be on both ears during bone-conduction testing.

Methods

Subjects:

- 19 normal-hearing adults (9 for HD 280 Pro, 10 for HDA 300; 19 for HDA 200).
- Pure tone thresholds within normal limits (octave and inter-octave frequencies 125 Hz to 8000 Hz); no known otologic disorders; screened by tympanometry and otoscopy.

Procedures:

Earphone Impedance & Sensitivity:

- Stimuli: octave and inter-octave pure tones at a nominal output level of 80 dB HL (exceptions: 70 dB HL at 125 Hz and 60 dB HL at 16,000 Hz), earphone loaded with IEC 60318 coupler (IEC 60318-1-2009).
- Measurements: voltage across earphone terminals and output sound pressure levels (SPLs).

Psychoacoustic Determination of RETSPLs:

- Measurements: pure-tone detection thresholds for all subjects at octave and inter-octave frequencies with all three earphones.
- HD 280 Pro procedure utilized Madsen Aurical audiometer, controlled by the AMTAS automated audiometry system. Test frequencies: octave and interoctave frequencies between 125-8000 Hz.
- HDA 300 procedure utilized GSI AudioStar Pro audiometer, manual modified Hughson-Westlake bracketing. Test frequencies: 125-16000 Hz.

Ambient Noise Attentuation:

- Stimulus: 75-dB SPL pink noise, presented by Audioscan Verifit system's external speaker, with subject seated approx. 1.5 feet from speaker with test ear facing the speaker.
- Ear canal SPL measurements made with ear unoccluded and occluded with each earphone.

Occlusion Effect:

- Stimulus: 80-dB HL (uncalibrated) pure-tone sweep presented via Radioear B-71 bone vibrator driven by Verifit external speaker port.
- SPL measurements made in ear canal contralateral to bone vibrator in both unoccluded and occluded conditions with each earphone.

Total Harmonic Distortion

- Stimuli: 90-dB HL pure tones at octave frequencies 500-8000 Hz presented via Benson CCA-100 Mini audiometer.
- Measurements: total harmonic distortion at each stimulus frequency measured in 60318 coupler.

Results

Sensitivity & Impedance:

- Sensitivity (dB output per input volt) was approximately 10 dB greater for the HDA 300 than for the other two earphones.
- Measured voltages at equal nominal output level were almost identical across all earphones (greatest observed difference was less than 0.33 dB), indicating essentially equivalent input impedance.

Earphone	dB/V	Avg ΔV (dB)
HDA 200	113.7	N/A
HD 280 Pro	113.0	0.0004
HDA 300	124.4	-0.2125

Table 1: Earphone sensitivity (dB/V at 1000 Hz) and average input voltage at 1000 Hz re: HDA 200 (Avg ΔV).

RETSPLs:

Formula for obtaining RETSPLs was ΔTz + ΔSPL + HDA 200 RETSPL = new RETSPL.

RETSPLs (HD 280 Pro)					
Freq	ΔSPL	ΔTz	RETSPL200	ΔSPL + ΔTz	RETSPL280
125	0.2	6.5	30.5	6.7	37.2
250	-10.0	5.5	18.0	-4.5	13.5
500	-5.1	0.9	11.0	-4.2	6.8
750	-3.5	-0.6	6.0	-4.2	1.8
1000	-1.8	-2.4	5.5	-4.1	1.4
1500	0.5	-2.3	5.5	-1.8	3.7
2000	-4.3	1.6	4.5	-2.6	1.9
3000	-7.7	1.3	2.5	-6.4	-3.9
4000	-4.9	-2.4	9.5	-7.3	2.2
6000	4.4	-7.5	17.0	-3.1	13.9
8000	8.3	-3.0	17.5	5.3	22.8

Table 2A: HD 280 Pro RETSPLs

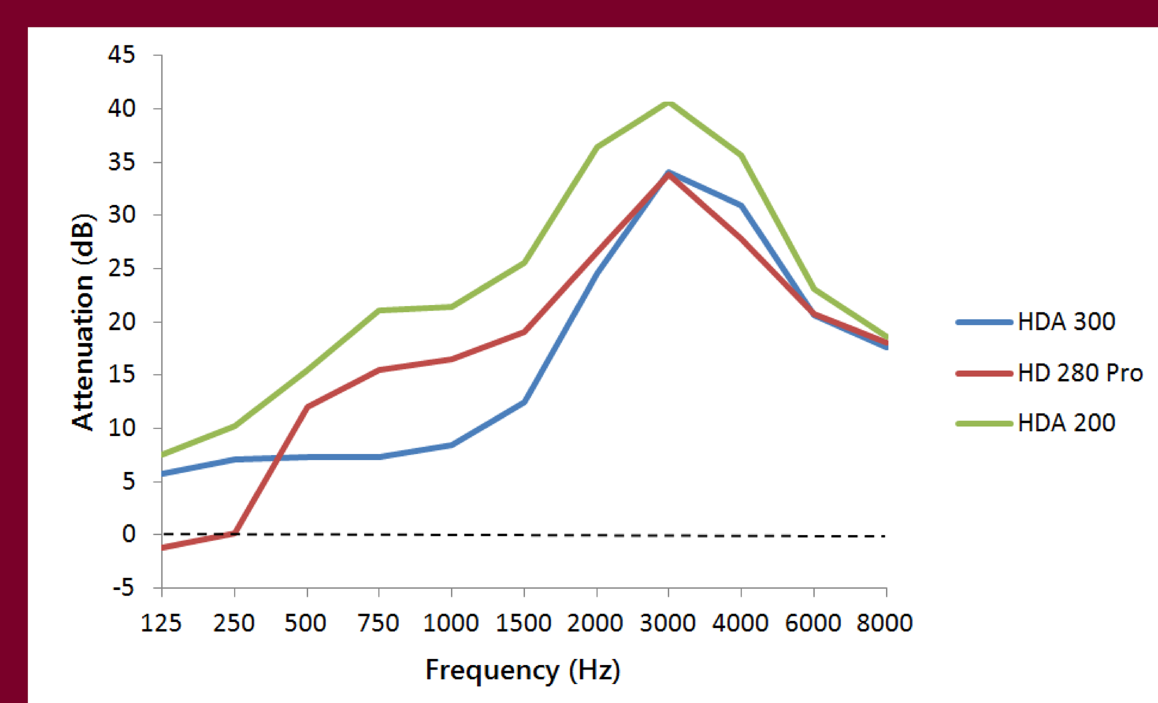
ΔTz = pure tone threshold difference between HDA 200 and test earphone

ΔSPL = coupler SPL difference between HDA 200 and test earphone

RETSPLs (HDA 300)					
Freq	ΔSPL	ΔTz	RETSPL200	ΔSPL + ΔTz	RETSPL300
125	14.7	-10.1	30.5	4.5	35.0
250	14.5	-11.5	18.0	3.0	21.0
500	15.9	-13.8	11.0	2.1	13.1
750	14.3	-11.6	6.0	2.7	8.7
1000	10.7	-12.0	5.5	-1.3	4.2
1500	6.5	-10.1	5.5	-3.6	1.9
2000	2.6	-8.0	4.5	-5.4	-0.9
3000	4.3	-8.4	2.5	-4.0	-1.5
4000	1.9	-9.6	9.5	-7.8	1.8
6000	8.7	-6.8	17.0	1.9	18.9
8000	11.5	-12.0	17.5	-0.5	17.0
9000	9.1	0.1	19.0	9.2	28.2
10000	5.4	-8.3	22.0	-2.9	19.1
11200	8.8	-11.5	23.0	-2.7	20.3
12500	5.6	-8.4	27.5	-2.8	24.7
14000	3.9	-1.1	35.0	2.7	37.7
16000	-0.3	-0.9	56.0	-1.2	54.9

Table 2B: HDA 300 RETSPLs

Figure 1. Ambient Noise Attenuation:

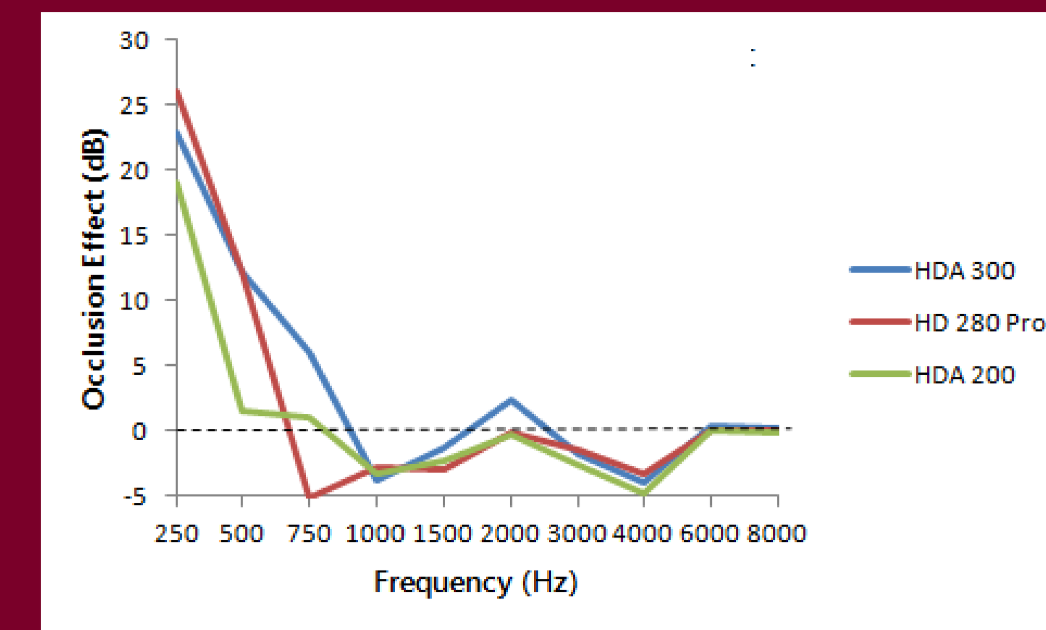


MPANLs (dB SPL)											
For testing at 125 Hz and up:				For testing at 250 Hz and up:				For testing at 500 Hz and up:			
Freq	300	280	200	Freq	300	280	200	Freq	300	280	200
125 Hz	34	27	36	125 Hz	38	31	40	125 Hz	48	41	50
250 Hz	27	20	30	250 Hz	27	20	30	250 Hz	37	30	40
500 Hz	22	27	31	500 Hz	22	27	31	500 Hz	22	27	31
1000 Hz	23	31	36	1000 Hz	23	31	36	1000 Hz	23	31	36
2000 Hz	42	44	53	2000 Hz	42	44	53	2000 Hz	42	44	53
4000 Hz	46	43	50	4000 Hz	46	43	50	4000 Hz	46	43	50
8000 Hz	32	32	33	8000 Hz	32	32	33	8000 Hz	32	32	33

Table 3: Maximum permissible ambient noise levels (MPANLs) for audiometric testing with each earphone

For further information, please contact Brandon Madsen (madse237@umn.edu).

Figure 2. Occlusion Effect:



Total Harmonic Distortion:

Total Harmonic Distortion (%)			
Freq	HDA 300	HD 280 Pro	HDA 200
500 Hz	0.03	0.11	0.10
1000 Hz	0.02	0.07	0.07
2000 Hz	0.19	0.51	0.21
4000 Hz	0.59	1.15	0.30
8000 Hz	0.00	0.00	0.00
Mean	0.17	0.37	0.13

Table 4: Total harmonic distortion in percent for each earphone

Analysis, Discussion, and Conclusions

- Sensitivity: HDA 300 earphones are more sensitive than the others by about 10 dB.
- Impedance: The voltage used to produce equal nominal output for each earphone is nearly identical, indicating essentially equivalent electrical input impedance.
- RETSPLs: The RETSPLs established in this study can be used to calibrate HDA 300 and HD 280 earphones for audiometric testing.
- Ambient noise attenuation: Attenuation was greatest for the HDA 200 (resulting in the highest MPANLs) and least for the HDA 300. This was true both on average and at each individual frequency. The most pronounced advantages of the HDA 200 over the HD 280 Pro were seen at 125-250 Hz and over the HDA 300 at 500-2000 Hz.
- Occlusion effect: All earphones had an occlusion effect less than 5 dB at 1000 Hz and above. Only the HDA 300 showed a notable occlusion effect at 750. Only the HDA 200 earphone showed a negligible occlusion effect at 500 Hz. The HDA 200 also had the smallest occlusion effect at 250 Hz.
- Total harmonic distortion: All earphones had total harmonic distortion low enough that it should not interfere with audiometric testing. Distortion levels were well within the requirements of the audiometer standards.
- Conclusions: All three earphones are reasonable to use for audiometric testing, given the right conditions (manual testing, low ambient noise levels, air-bone gaps not too large). The HDA 200 is the most versatile and the best-suited to automated audiometry, noisy environments, and avoidance of masking dilemmas, but it is out of production.

References

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IEC 60318-1-2009. Electroacoustics – Simulators of human head and ear – Part 1: Ear simulator for the measurement of supra-aural and circumaural earphones. Geneva: International Electrotechnical Commission.

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Acknowledgments

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