Tutorial

The Acoustic Test Environment for Hearing Testing

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Robert H. Margolis*†
Brandon Madsen*

Abstract

Background: Audiology clinics traditionally employ expensive, prefabricated sound rooms to create an environment that is sufficiently quiet for accurate hearing tests. There is seldom any analysis of the need for or benefit from such enclosures. There may be less expensive methods that would decrease the cost of and increase access to hearing testing.

Purpose: This report provides information concerning the need for and effectiveness of sound rooms and an analysis of the audiometric test ranges for various earphone/room combinations.

Research Design: Acoustic measurements made in four rooms were analyzed with the attenuation provided by various earphone designs to determine the maximum permissible ambient noise levels and the corresponding audiometric test ranges.

Study Sample: The measurements and calculations were performed with four test rooms and five earphone designs.

Data Collection and Analysis: Ambient noise levels and earphone attenuation characteristics were used to calculate the noise levels that reach the ear. Those were compared to the maximum permissible ambient noise levels that are provided in ANSI S3.1-1999 or calculated from measured attenuation levels. These measurements were used to calculate testable ranges for each room/earphone combination.

Results: The various room/earphone combinations resulted in minimum test levels that ranged from −10 to 20 dB HL at various test frequencies.

Conclusions: When the actual benefits of expensive prefabricated sound rooms are assessed based on the range of hearing levels that can be tested, the effectiveness of that approach becomes highly questionable. Less expensive methods based on planning the clinic space, use of inexpensive sound treatments, and selecting an appropriate earphone can be effective in almost any space that would be used for hearing testing.

Key Words: ambient noise, audiometry, circumaural earphone, earphone, hearing test, insert earphone, maximum permissible ambient noise level, sound room, supra-aural earphone

Abbreviations: MPANL = maximum permissible ambient noise level; RETSPL = reference equivalent threshold sound pressure level

*University of Minnesota, Department of Otolaryngology, Minneapolis, MN; †Audiology Incorporated, Arden Hills, MN

Corresponding author: Robert H. Margolis, University of Minnesota, Department of Otolaryngology, Minneapolis, MN 55455; E-mail: rhmargo001@gmail.com.

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INTRODUCTION

> "We buy $30,000 sound rooms so we can test normal-hearing people."—Lisa L. Hunter, Ph.D., personal communication

Major league baseball players arrive at the ballpark two or three hours before game time so they can "warm up". In addition to eating, drinking, sleeping, and video games, the warm up consists of "playing catch" as we used to call it, and "wind sprints," defined as 10 sec of three-quarter-speed running followed by 5 min of discussion. Then they warm up again before every half inning, 17 or 18 times during the game. Fans spend thousands of hours every summer day watching the ritual. Athletes in sports that actually require some level of fitness are able to compete without this dedication to proper preparation.

Why do they do this? Tradition.

There are many things we do in audiology for the same reason. One of them is our obsession with the sound booth—a manufactured chamber that provides attenuation of ambient sound. In this article we will examine the need (or lack thereof) for the sound booth in hearing testing.

The first author's first audiology job was in a second-floor ENT office on a busy street in downtown Canton, OH. The resourceful otolaryngologist slapped some acoustic tile on the wall of a small room, laid a rug on the floor, and for a hundred 1967 dollars we had a test room. We got perfectly good audiograms. It was quiet in that room.

For the most part, our textbooks teach us that specially built sound rooms are required for clinical hearing testing. Here are some samples.

> "… it is virtually imperative that a commercially built sound-treated enclosure is used."—Roeser et al (2000, 240)

> "Diagnostic hearing testing must be done in a specially designed sound-attenuating test room (often called a sound booth or test suite) …"—Kramer (2008, 120)

> "Pure-tone and other forms of audiometric testing are performed in a sound-treated booth or suite."—Valente (2009, 17)

But earlier one of the most popular basic textbooks in audiology said

> "Actually, however, unless it is intended for research studies involving precise measurement of normal ears, it is not necessary to have an expensive, highly isolated room."—Newby and Popelka (1985, 117)

And another suggested that there may be another way to accomplish the desired ambient noise level.

> "There are two major ways in which ambient room noise may be attenuated: through the use of specially designed earphone enclosures and by constructing sound-treated chambers…"—Martin (1986, 63)

It is the custom in the United States, when designing clinics for hearing testing, to install expensive prefabricated sound rooms, without evaluation of the need and without consideration for other methods for creating a suitable test environment. Prefabricated sound rooms can cost as much as $30,000 and the preparation of the space for installation can force the cost up to as much as $150,000. Let us examine the cost-effectiveness of this approach.

AMBIENT NOISE IN THE TEST ENVIRONMENT

There are many sources of noise in a building. It is important to distinguish between the steady-state noise and transient noise that may be produced by foot traffic, talking, telephones and other communication devices, electronic and mechanical equipment, street traffic, weather, construction, and many other sources. Both steady-state and transient noise vary during the course of a day. Measurements at a single point in time may not represent the potential interfering effect of ambient noise on a particular hearing test.

Most of the discussion of the interfering effects of ambient noise are focused on acoustic effects of reducing the audibility of test signals. But ambient noise, especially the transient variety, also creates distractions which can compromise test results in ways that are unrelated to audibility. A distracted patient does not produce accurate, reliable test results. The best solution to transient noise is to locate the test room away from noise sources, eliminate electronic equipment from the area, use inexpensive sound treatments, and control traffic patterns so that there is no unnecessary foot traffic in the area. This requires careful planning but can produce significant cost savings. The analyses presented in this article pertain to steady-state ambient noise and assume that other sources of noise are avoided by careful planning of the clinic space.

MAXIMUM PERMISSIBLE SOUND LEVELS

The maximum sound level that does not interfere with measurement of auditory thresholds can be determined from psychoacoustic data on auditory masking. The softest audible pure-tone sound level in a background of white noise is about 18 dB higher than the level of the noise in a 1-Hz band (Hawkins and Stevens, 1950). When the noise level is measured over its entire bandwidth, the signal-to-noise ratio at threshold is about −13 dB (Stuart, 1994). Only the noise in the frequency region of the tone affects the audibility of the tone. The band that is effective in masking the tone is the "critical band" (Fletcher, 1940). The width of the critical band has been controversial and it ranges from 60 to 160 Hz at 1000 Hz, depending on the measurement technique. The critical bandwidth increases with frequency in a roughly logarithmic fashion. Auditory masking is nearly a linear

phenomenon. That is, there is a 10-dB increase in masked threshold for every 10-dB increase in the masker level.

These basic principles of auditory masking provide a means to determine the maximum noise levels that will not interfere with the audibility of a pure-tone signal at a specific hearing level. Those values are provided in the ANSI standard—ANSI S3.1-1999 (R2013), Maximum Permissible Ambient Noise Levels (MPANL) for Audiometric Test Rooms. The authors of the standard, who were not obsessed with prefabricated rooms, defined an audiometric test room (also known as an audiometric test area in case there are not any walls) as an "enclosed space used for hearing testing." In a footnote the standard allows that the test space may be a prefabricated room.

The MPANL is defined in the standard as the noise level "that will produce negligible masking of pure tones presented at reference equivalent threshold levels" as specified in the audiometer standard (ANSI S3.6-2010). Stated differently, the MPANL is the maximum noise level that will permit testing at 0 dB HL without threshold elevation by ambient noise. Although the audiometer standard requires stimuli as low as −10 dB HL, the MPANL standard specifies noise levels that allow testing down to 0 dB HL.

The MPANL standard ANSI S3.1-1999 recognizes that in different situations, different minimum test levels are appropriate:

> The Standard specifies that MPANLs should be adjusted appropriately when hearing thresholds for pure tones are measured above and below 0 dB HL.—(p. 2)

Accordingly, in determining the appropriate MPANL for a given test room, the audiologist should decide at what minimum levels they want to be able to measure thresholds. If testing hearing thresholds down to 20 dB HL is acceptable, then 20 dB can be added to the standard MPANLs. If it is important to test down to −10 dB HL, then 10 dB must be subtracted from the standard MPANLs.

METHODS FOR ELIMINATING UNWANTED SOUND

Although the most common method for reducing ambient noise levels is the sound room, there are other effective methods. Locating the test room away from noise sources and controlling traffic patterns have been mentioned. Martin (1986, quoted above) pointed out that headphone design can be an effective method for isolating the ear from ambient noise. For many decades, the most common transducer type for audiometry has been the supra-aural earphone of the type manufactured by Telephonics Corporation. The supra-aural earphone is the least effective design of those used for audiometry for attenuating ambient noise.

Maclennan-Smith et al (2013) used a unique headphone arrangement to control ambient noise during hearing testing. They used insert earphones (Etymotic ER3A) in conjunction with a head-worn audiometer built into sound attenuating enclosures. The combination of the insert earphones and circumaural enclosures effectively reduced the ambient noise to levels that permitted accurate testing of retirement home residents tested in "a quiet furnished room" in the facility. There were no significant differences in air and bone conduction thresholds testing at the facility and in sound rooms.

The empirical approach taken by Maclennan-Smith et al provides strong evidence that accurate hearing testing can be achieved in environments other than sound rooms. The lowest levels that can be tested in a test room can be determined from measurements of the actual noise levels and the attenuation characteristics of earphones. Results for three different rooms and five different earphone designs are presented below.

THE TEST ROOMS

The four test rooms are described below. Ambient noise measurements made in each of the rooms are provided in Table 1.

Room 1—two-room double-wall prefabricated sound room. This room is the Audiology Research Laboratory at the University of Minnesota Medical Center and is located in the Audiology Clinic with six similar two-room suites. The measurements were made during clinic operation.

Room 2—single-wall sound room. This 7′4″ × 7′ prefabricated booth is installed inside a clinic room in a busy ENT Clinic. The booth has a carpeted floor and a door that opens into the clinic room. The clinic room containing the booth has one door that opens into the clinic's heavily used main hallway. The measurements were made during clinic operation.

Room 3—office. This is a 12′ × 12′ space located on the fifth floor of an office building in the University of

Table 1. One-third Octave Band Ambient Noise Levels (dB SPL) in Four Test Rooms

	Ambient Sound Levels			
Freq (Hz)	Rm 1	Rm 2	Rm 3	Rm 4
125	27.8	24.9	43.7	46.8
250	16.1	9.9	36.3	43.5
500	5.4	7.7	35.4	31.4
800	5.8	9.0	30.9	30.0
1000	6	9.1	29.5	37.3
1600	7.1	11.5	25.8	25.5
2000	7.7	10.1	24.4	21.0
3150	9.5	10.9	24.4	28.3
4000	10.5	11.7	24.7	25.5
6300	12.1	12.5	25.9	25.2
8000	13.1	13.5	27.3	23.6

Freq = frequency; Rm = room.

Minnesota Hospital complex. The room has a window facing the street where the main entrance to the outpatient clinic building is located. The measurements were made during a normal work day.

Room 4—student workroom. This is a 10′ × 15′ windowless room with a 10′ ceiling located five floors underground. It serves as a student/intern workroom at the National Center for Rehabilitative Auditory Research at the VA Medical Center in Portland, OR. The room is filled with desks, computers, and shelves, and it has a door that opens into a dead-end hallway which does not receive much incidental foot traffic. The measurements were made during a normal work day.

THE EARPHONES

Five earphones were analyzed for their performance in the three test rooms. Three (Sennheiser HDA 200, HDA 300, and HD 280 Pro) were evaluated to determine their appropriateness for routine audiometry by Madsen and Margolis (2014). Two others (Telephonics TDH50, Etymotic ER3A) were evaluated based on published data. Ambient noise attenuation measurements and MPANLs for each earphone are provided in Table 2.

Telephonics TDH50 earphones are the latest version of the supra-aural earphone that has been in use since the 1950s. Because of its supra-aural design it has relatively poor ambient noise attenuation and creates a large occlusion effect that complicates bone-conduction testing.

Sennheiser HDA 200 earphones have been in use in audiology clinics for many years, primarily for extended high-frequency testing. The reference equivalent threshold sound pressure levels (RETSPLs) for both conventional (125–8000 Hz) and extended high frequencies (9000–16000 Hz) appeared in an appendix of the 2004 version of the audiometer standard (ANSI S3.6-2004) and in the main body of the 2010 version (ANSI S3.6-2010). The transducer is built into a circumaural hearing protection device that provides a high level of ambient noise attenuation. Although these earphones have many desirable features they have not been used extensively for audiometry in the conventional frequency range. The HDA 200 earphone has been discontinued from production.

Sennheiser HDA 300 earphones are now offered as the replacement for the HDA 200 model. The transducer is built into a circumaural enclosure that does not provide as much ambient noise attenuation as the HDA 200. The frequency response is similar to its predecessor so it is equally usable for testing both conventional frequencies and extended high frequencies. The RETSPLs are not yet in the audiometer standard but are available in Madsen and Margolis (2014).

The Sennheiser HD 280 Pro headset is a consumer product that is used primarily by musicians and music engineers. It has a circumaural design with ambient noise attenuation and occlusion effect that is better than the HDA 300 but inferior to the HDA 200. It represents a low-cost alternative to earphones most commonly used for audiometry.

Etymotic ER3A earphones (also sold as E-A-R Tone 3A earphones) are insert earphones that can be calibrated for pure-tone audiometry. RETSPLs for this earphone are in the audiometer standard. When deeply inserted they produce a high level of ambient noise attenuation and a small occlusion effect relative to supra-aural earphones. With less deep insertion the ambient noise attenuation decreases and the occlusion effect increases.

Ambient noise attenuation values shown in Table 1 were measured with probe tubes inserted into the ear canal which provided signals that could be measured with and without the earphone in place. (See Madsen and Margolis, 2014, for more information.) The ambient

Table 2. Ambient Noise Attenuation (Attn) in dB and MPANL in dB SPL for Circumaural Earphones (Senheiser HDA 200, HDA 300, HD 280 Pro), Insert Earphones (Etymotic ER3A), and Supra-aural Earphones (Telephonics TDH50)

	Sennheiser HDA 200*		Sennheiser HDA 300*		Sennheiser HD 280 Pro*		Etymotic ER3A "Deeply inserted"†		Etymotic ER3A "Deeper" Insertion‡		Etymotic ER3A "Shallow" Insertion‡		Telephonics TDH50‡,§	
Freq (Hz)	Attn	MPANL	Attn	MPANL	Attn	MPANL	Attn	MPANL	Attn	MPANL	Attn	MPANL	Attn	MPANL
125	8	40	6	38	−1	31	32	62					7	34
250	10	30	7	27	0	20	36	48	23	35	14	26	5	20
500	16	31	7	22	12	27	38	45	26	33	15	22	6	16
1000	21	36	8	23	17	31	37	42	28	33	17	22	12	21
2000	36	53	25	42	27	44	33	44	32	43	25	36	17	29
4000	36	50	31	46	28	43	39	45	37	43	33	39	22	32
8000	19	33	18	32	18	32	43	51	38¶	47	33¶	42	23	32

*Madsen and Margolis (2014).
†Berger and Killion (1989).
‡Clark and Roeser (1988).
§ANSI S3.13-1999.
¶6000 Hz; 8000 Hz not reported.

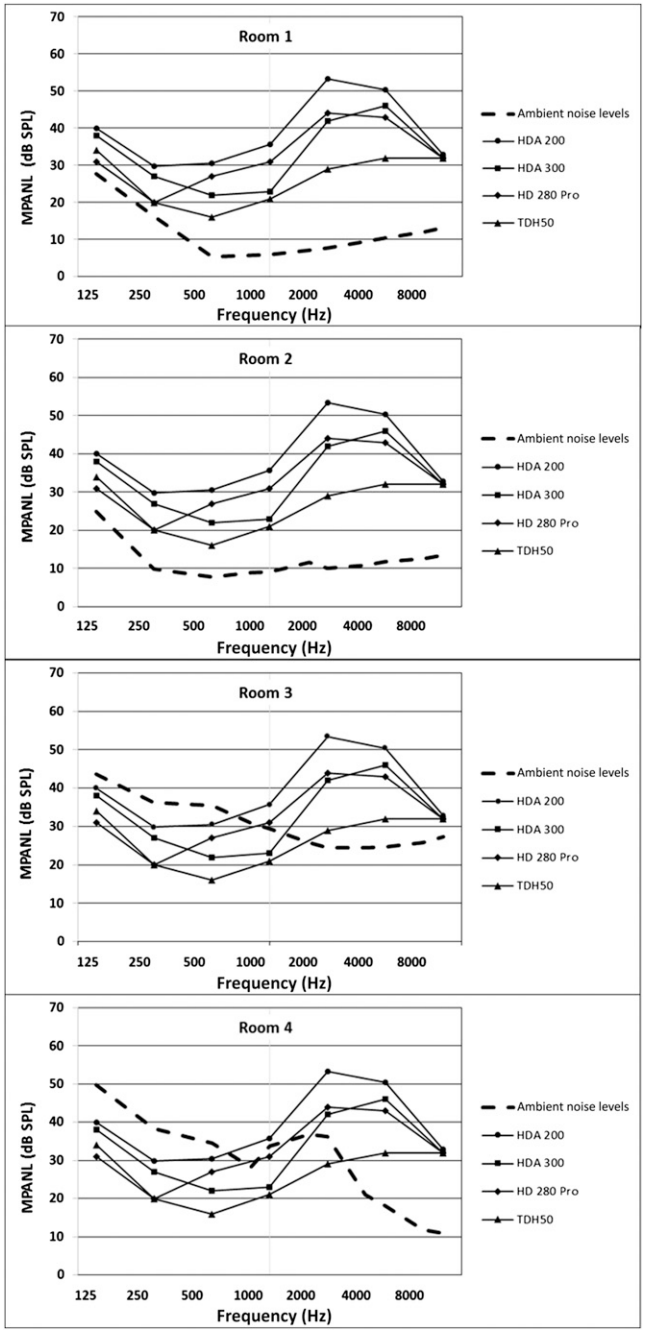

Figure 1. MPANLs for four earphones compared to ambient noise levels (sound levels) in four test rooms. MPANLs and their sources are given in Table 2. The dashed lines are the third octave ambient noise levels (dB SPL).

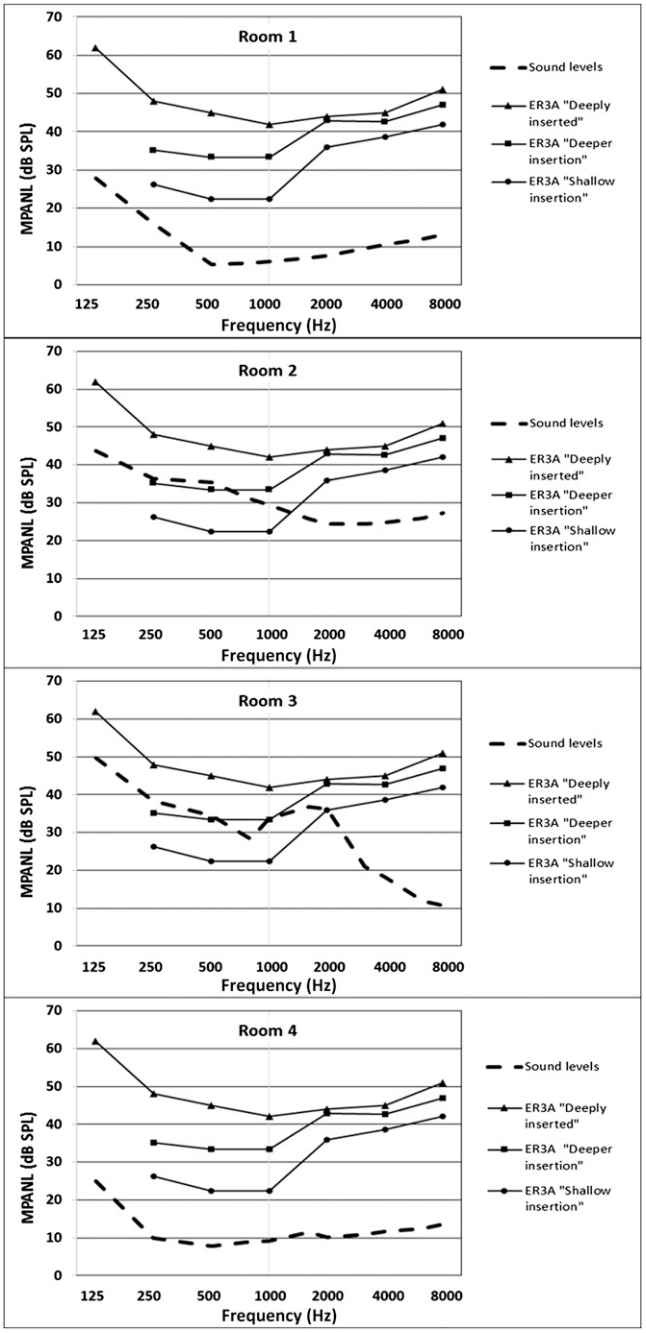

Figure 2. MPANLs for insert earphones placed with three insertions depths in three test rooms. MPANLs and their sources are given in Table 2. The dashed lines are the third octave ambient noise levels (dB SPL).

noise attenuation provided by any of the earphones is dependent on the adequacy of the coupling to the head. Perhaps the ER3A insert earphones are most prone to variation due to placement because of the wide variance of the insertion depth accomplished by audiologists in practice. Table 2 provides three sets of values for that earphone from two studies. Two of these sets of values were obtained with deep insertion, probably deeper than most audiologists employ in practice. There are large differences in the two sets of attenuation values. The shallow insertion produced less ambient noise attenuation as expected.

EVALUATING THE ADEQUACY OF TEST ROOMS

The adequacy of a test room with regard to steady-state ambient noise levels can be evaluated

by examining the relationship between the MPANLs and the measured noise levels. MPANLs for the transducers evaluated for this report were obtained from a variety of sources indicated in Table 2. The figures show these comparisons for circumaural and supra-aural earphones (Figure 1) and insert earphones at different insertion depths (Figure 2) in the four test rooms. If the MPANLs exceed the measured noise levels the room is sufficiently quiet for testing without masking effects by the ambient noise. The MPANLs in Figures 1 and 2 represent the maximum noise levels that permit testing down to a level of 0 dB HL. As the standard allows, the values can be adjusted up or down if it is desirable to test to higher or lower levels than 0 dB HL.

MPANLs were compared to measurements of ambient sound levels made in each of the test rooms. Sound measurements were made with a commercial sound level meter (Larson Davis System 824) with a diffuse field microphone (Larson Davis 2559) at the position that would normally be occupied by the listener. All measures were 1/3 octave root-mean-square band levels (relative to 20 μPa).

The results shown in Figure 1 indicate that noise levels in Rooms 1 and 2 are below the MPANLs for all earphones at all frequencies. In the other sound rooms the MPANLs are mostly above the ambient sound levels at frequencies above 1000 Hz and below the noise levels at frequencies below 1000 Hz indicating restricted test ranges at lower frequencies.

The results shown in Figure 2 indicate that noise levels in Rooms 1 and 2 are below the MPANLs for insert earphones at all insertion depths indicating that thresholds of 0 dB HL and below can be tested in that room. In the other rooms, the MPANLs are mostly above the ambient sound levels at frequencies above 1 kHz. At lower frequencies the MPANLs for the deepest insertion depth are above the ambient noise levels but below the noise levels for the shallower insertion depths.

Perhaps a more useful way to view these results is to show the range of threshold hearing levels that can be

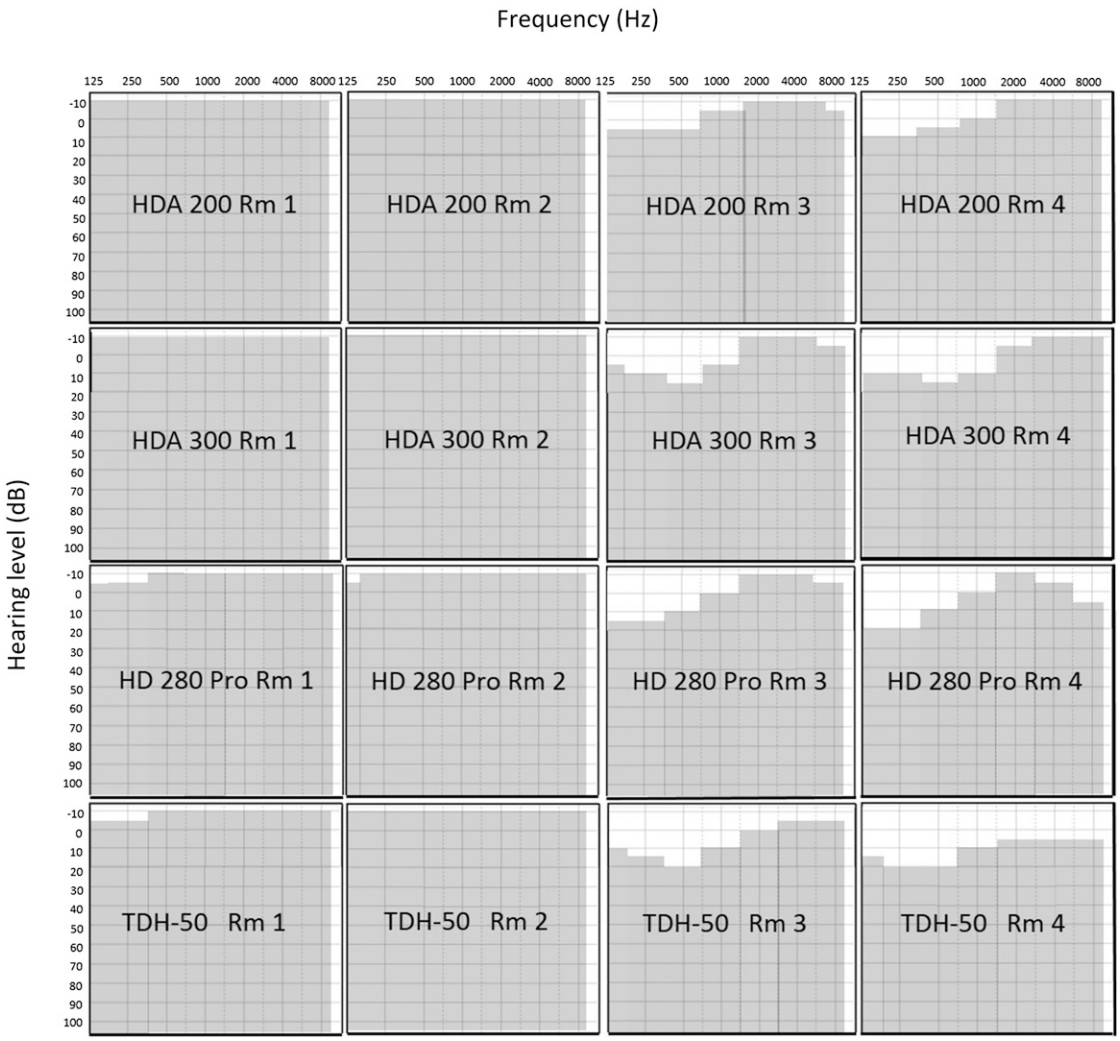

Figure 3. Testable ranges for four earphones in four test rooms. The shaded areas indicate the hearing levels that can be tested without interference from ambient noise.

tested with each combination of earphone and test room. Those are shown by the shaded areas in Figures 3 and 4. Figure 3 shows the testable ranges for the supra-aural and circumaural earphones. In the prefabricated sound rooms (Rooms 1 and 2) all three earphones can be used to test down to levels of 0 dB HL and lower.

In Room 3, the HDA 200 earphones can be used to test down to 5 dB HL at low frequencies, −10 dB HL in to 2000–6000 Hz range, and −5 dB HL at 8000 Hz. Testable ranges for Room 4 are similar to those for Room 3.

The testable ranges with insert earphones are shown in Figure 4 for the three rooms and various insertion depths. In Rooms 1 and 2 the testable range extends to −10 dB HL for all insertion depths. The deep insertion depth provides a testable range to −10 dB HL in the other rooms as well. Shallower insertion depths limit the testable range but in no case was the minimum testable threshold higher than 15 dB HL. In practice, audiologists are reluctant to use the deepest insertion depth that results in the "Deep 1" results in Figure 4. Probably the "shallow" results are more consistent with actual use. The comfort and safety issues associated with deep insertion of insert earphones are disadvantages.

DISCUSSION

The design of a test environment and the selection of earphones is inextricably linked to the determination of the lowest level at which it is desirable to obtain an accurate threshold. In an analysis of three large databases of audiograms of normal-hearing listeners obtained by routine clinical testing methods by audiologists, there was a remarkably low occurrence of thresholds below 0 dB HL (Margolis et al, 2015). We hypothesized that this finding was at least in part due to tester bias. We termed this phenomenon the "Good Enough Bias" and suggested that audiologists not place the same importance on identifying low thresholds (<0 dB HL) as they do on higher thresholds. Ambient noise in the test environment may also contribute to this finding. The Margolis et al (2015) study suggests that audiologists often tacitly decide that thresholds below 0 dB HL are not important to measure.

Clinics that are focused on testing hearing-impaired patients and not on normal-hearing patients have a wide range of choices of test environment and transducers. The clinics can avoid significant expenditures by using ordinary rooms and circumaural earphones. Ambient noise levels in these spaces can be controlled by (a) selecting a location that is away from noise sources; (b) use of sound treatments such as acoustic tile, carpets, and wall coverings; (c) controlling the traffic flow away from the test room; and (d) the use of earphones with sound-attenuating enclosures. The results in Figure 3 indicate that for the test rooms and transducers that were evaluated, there is no significant advantage of two-room double-wall sound suite over a single prefabricated single-wall room.

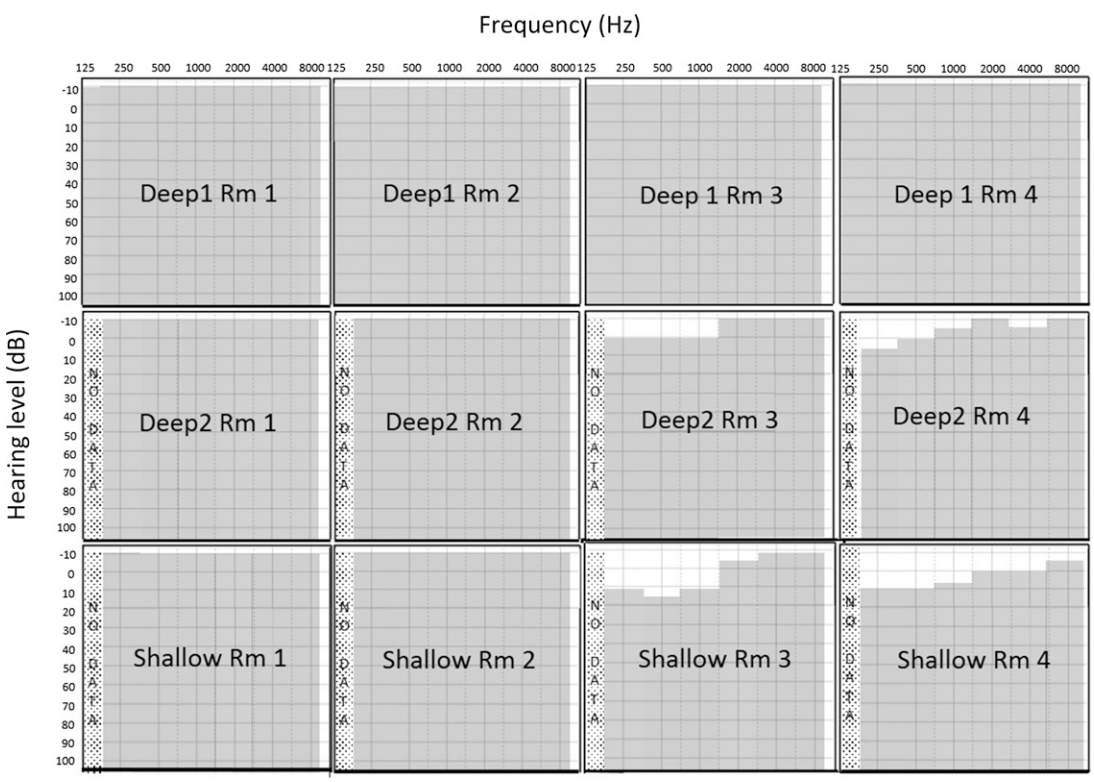

Figure 4. Testable ranges for insert earphones placed with three insertion depths in three test rooms. The shaded areas indicate the hearing levels that can be tested without interference from ambient noise.

There are four limitations to the generalizability of these results. First, Rooms 3 and 4 were selected arbitrarily as examples. They were not specifically selected for use as audiometric test rooms. Rooms selected for hearing testing may have lower noise levels by employing the methods described above. Second, this analysis does not take into consideration transient noise from sources such as foot traffic, talking, street noise, and electronic equipment. Transient noise affects the audibility of test signals due to masking but also creates distractions that can affect test accuracy. These sources can be controlled by planning the layout of the clinic. Third, this analysis does not consider the hearing loss characteristics of the population served by the clinic. The worst-case combination of earphone and test room is the TDH-50 earphone in Rooms 3 and 4 for which thresholds can be tested down to 20 dB HL in the low frequencies and 5 dB HL in the high frequencies. These levels are low enough that all patients with communicatively significant hearing losses would be tested accurately. For diagnostic purposes it is sometimes beneficial to test to lower levels for identification of mild effects of various diseases such as otitis media. Similarly, for monitoring treatment effects it is sometime advantageous to test to lower levels. An earphone with greater ambient noise attenuation would eliminate those limitations. Fourth, the analysis pertains only to procedures in which the ear is covered or occluded by an earphone. Other tests in which the test ear is uncovered, such as bone-conduction and sound-field testing require lower MPANLs. Bone-conduction testing can be performed with a circumaural earphone that minimizes the occlusion effect, such as the Sennheiser HDA 200, to exclude ambient noise. In that case the HDA 200 MPANLs would apply to bone-conduction testing. An analysis such as the one in this article should be performed for testing in open-ear conditions.

The HDA 200 earphone is superior to all others except the insert earphone with deep insertion. Unfortunately, that earphone is no longer in production. There is a need for an audiometric earphone with similar characteristics. Although the cost of the HDA 200 and HDA 300 earphones is high relative to other earphones on the consumer and industry markets, that cost is far exceeded by the cost of a sound booth. The HD 280 Pro, a consumer product priced at $100 per pair, is an excellent low-cost alternative that can be adequate in some environments.

The results shown in Figures 3 and 4 indicate that even in an expensive sound room with standard earphones it is often not possible to test down to −10 dB HL. This calls into question the wisdom of requiring audiometers to be capable of testing to that level as specified in the audiometer standard (ANSI S3.6-2010).

When one examines the benefits of sound rooms that are evident in Figures 3 and 4, the effectiveness of that approach for creating an acceptable environment for hearing testing becomes doubtful. Buildings that house audiology clinics are seldom designed with the hearing-test environmental acoustics in mind. Some very simple planning that takes into account traffic patterns and noise sources could avoid significant costs related to prefabricated sound rooms. Earphone designs can contribute as well. A high-quality earphone like the now-unavailable Sennheiser HDA 200 earphone could decrease costs and increase access to hearing testing.

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REFERENCES

American National Standards Institute (ANSI). (2010) *Specification for Audiometers.* ANSI S3.6-2010. New York, NY: ANSI.

American National Standards Institute (ANSI). (1999) *Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms.* ANSI S3.1-1999 R2013. New York, NY: ANSI.

Berger EH, Killion MC. (1989) Comparison of the noise attenuation of three audiometric earphones, with additional data on masking near threshold. *J Acoust Soc Am* 86(4):1392–1403.

Clark JL, Roeser RJ. (1988) Three studies comparing performance of the ER-3A tubephone with the TDH-50P earphone. *Ear Hear* 9 (5):268–274.

Fletcher H. (1940) Auditory patterns. *Rev Mod Phys* 12:47–65.

Hawkins JE, Stevens SS. (1950) The masking of pure tones and of speech by white noise. *J Acoust Soc Am* 22:6–13.

Kramer S. (2008) *Audiology: Science to Practice*. 1st ed. San Diego, CA: Plural Publishing.

Maclennan-Smith F, Swanepoel W, Hall JW, III. (2013) Validity of diagnostic pure-tone audiometry without a sound-treated environment in older adults. *Int J Audiol* 52(2):66–73.

Madsen BM, Margolis RH. (2014) Audiometric Properties of Three Circumaural Earphones. Poster presented to the American Auditory Society, March 6, 2014, Scottsdale, AZ. http://audiologyincorporated.com/articles.

Margolis RH, Wilson RH, Popelka GR, Eikelboom RH, Swanepoel DW, Saly GL. (2015) Distribution Characteristics of Normal Pure-Tone Thresholds. *Int J Audiol* 4:[Epub ahead of print].

Martin FN. (1986) *Introduction to Audiology*. 3rd ed. Upper Saddle River, NJ: Prentice Hall.

Newby HA, Popelka GR. (1985) *Audiology*. 5th ed. Upper Saddle River, NJ: Prentice Hall.

Roeser RJ, Buckley KA, Stickney GS. (2000) In *Audiology: Diagnosis*. Roeser, Valente, Hosford-Dunn. eds. New York, NY: Thieme.

Stuart RJ. (1994) Noise: methods for estimating detectability and threshold. *J Audio Eng Soc* 42:124–140.

Valente M. (2009) *Pure-tone Audiometry and Masking*. 1st ed. San Diego, CA: Plural Publishing, Inc.