Effect of Ear Canal Occlusion on Pure-Tone Threshold Sensitivity

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Abstract

This study sought to quantify the effects of varying the degree of ear canal occlusion on pure-tone threshold sensitivity. Thresholds were obtained from each ear of five normal-hearing adults without occlusion, with complete occlusion, and with partial occlusion estimated to be 40–60% and 60–80%. A commercial lubricant was used in the completely occluded condition to eliminate possible acoustic leakage. Results showed a reduction of threshold sensitivity in all occluded conditions, with the greatest effect in frequencies above 1000 Hz. Only in the completely occluded condition were frequencies below 1000 Hz affected. In the partially occluded conditions, thresholds decreased by an average 7.5 dB and 13.0 dB across frequency for the 40–60% and 60–80% conditions respectively. At frequencies above 1000 Hz, the average threshold shifts for the two partially occluded conditions were 10.0 dB and 16.8 dB respectively. The implications of these findings on routine pure-tone audiometric procedures, with specific relevance for industrial hearing conservation programs, are discussed.

Key Words: Occlusion, pure-tone thresholds, threshold sensitivity

Abbreviations: STS = standard threshold shift

Sumario

Este estudio buscó cuantificar los efectos de variar el grado de oclusión del canal auditivo sobre la sensibilidad a tonos puros. Los umbrales se obtuvieron de cada oído en cinco adultos normo-oyentes, sin oclusión, con oclusión completa y con oclusión parcial, considerada del 40–60% y del 60–80%. Se usó un lubricante comercial para la condición de oclusión completa, para eliminar una posible fuga acústica. Los resultados mostraron una reducción en la sensibilidad umbral en todas las condiciones ocluidas, con el mayor efecto en las frecuencias por encima de 1000 Hz. Las frecuencias por debajo de 1000 Hz sólo se afectaron en la condición de oclusión completa. En las condiciones de oclusión parcial, los umbrales disminuyeron un promedio de 7.5 db y 13.0 dB por frecuencia, para las condiciones de 40–60% y 60–80% respectivamente. En frecuencias por encima de 1000 Hz, los cambios promedios de umbral para las dos condiciones de oclusión parcial fueron de 10.0 db y 16.8 dB respectivamente. Se discuten las implicaciones de estos hallazgos en los procedimientos audiométricos tonales rutinarios, con especial relevancia para los programas de conservación auditiva industrial.

Palabras Clave: Oclusión, umbrales tonales puros, sensibilidad umbral

Abreviaturas: STS = cambio estándar de umbral

Research and clinical practice have identified a number of variables that will affect pure-tone thresholds, including background noise, type and placement of earphones, and psychophysical method used (Roeser and Clark, 2000). While the effects of these variables have been documented by a multitude of studies, one important variable, the effects of partial ear canal occlusion, has yet to be thoroughly studied.

Ear canal occlusion occurs most frequently due to excessive cerumen and is an important variable due to its prevalence. In children, the prevalence of occlusion due to excessive cerumen is estimated at about 10% (Roche et al, 1978; Bricco, 1985). Findings on prevalence rates in adults in the general population have varied considerably, but most studies have reported data averaging 5–8% (Perry, 1957; Hopkinson, 1981; Cooper 1985; Gleitman et al, 1992).

While those in the general populations show a relatively low prevalence of ear canal occlusion from excessive or impacted cerumen, studies with elderly subjects and those having developmental delays clearly document significantly greater cerumen accumulations. As individuals age, the relative secretions of the ceruminous glands decrease due to a reduction in the absolute number of ceruminous glands in the ear canal. As a consequence of this process, the cerumen becomes drier. When coupled with an increase in the number and coarseness of cilia in the ear canal, especially in males, the result is a linear increase in the percentage of elderly patients with excessive cerumen (Ruby, 1986; Gleitman et al, 1992). Of note is the work of Mahoney (1987, 1993), who carried out longitudinal studies on the prevalence of excessive cerumen in nursing home residents and found 34–57% with "moderate to large" amounts of cerumen.

Individuals with developmental delays are known to have excessive amounts of cerumen, ranging from 22 to 36% (Nudo, 1965; Fulton and Griffin, 1967; Brister et al, 1986; Dahle and McCollister, 1986). One longitudinal study over the course of 12 years documented prevalence rates of excessive and impacted cerumen for 117 adults with developmental delays (Crandell and Roeser, 1993). Excessive/impacted cerumen was defined as occluding debris in the ear canal of 50% or greater. Of the 586 otoscopic examinations performed in this study, 165 (28%) revealed excessive or impacted cerumen. Although the propensity for those with developmental delays to have excessive cerumen has been well documented, the pathophysiology for this finding is still unknown.

To date, only one published report is available on the effects of varying the degree of ear canal occlusion on pure-tone thresholds. Chandler (1962) showed that when the ear canal is occluded from 80–100%, threshold sensitivity at 2000 Hz and above is systematically reduced by an average of 13–20 dB. However, Chandler's data were based on only two subjects.

Results from the above studies unquestionably document the fact that ear canal occlusion due to excessive cerumen is a common clinical observation. As there is only one published investigation in this area, the present study was designed to add additional data on this often observed clinical condition. The specific purpose of the study was to determine if partial ear canal occlusion has the potential to impact routine threshold audiometry with adult subjects.

METHODS

Subject

Five adults (one female and four males) with normal threshold sensitivity (20 dB HL or better; ANSI, 1996) at octave frequencies from 250–8000 Hz, with no prior history of otologic disease, participated as subjects. The age range was from 20 to 35 years (mean = 24.3 years).

Instrumentation/Procedures

Otoscopic inspection was performed on each subject to ensure an unoccluded ear canal. A baseline audiogram (without occlusion) was obtained at octave frequencies from 250–8000 Hz and at half octave frequencies 3000 and 6000 Hz using the Modified Hughson-Westlake procedure in 5 dB steps (Carhart and Jerger, 1959). Upon completion of baseline threshold testing, an ear impression was made for each ear with the following procedure. Initially, a foam block was placed past the second bend of

Occluding Conditions
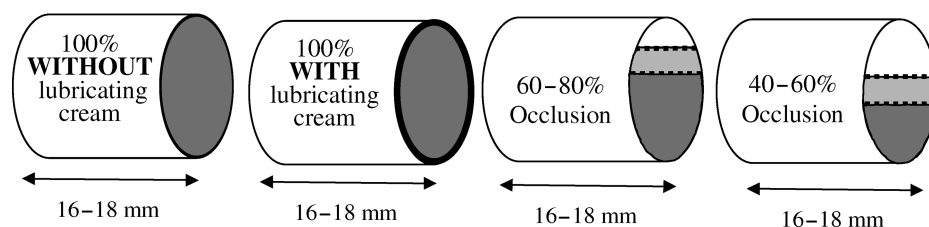
Figure 1. Degree of occlusion for each of the four conditions utilized for this study.

each ear canal, and the impression material was prepared and placed into the ear canal adjacent to the foam block, occluding the void until the helix and concha areas were completely filled. After the requisite curing time (i.e., 10 minutes), the impression was removed. The impression material was carefully modified in order to simulate occlusion as follows. First, the bore from the second bend to the foam plug and the outer portion that encapsulated the auditory meatus, concha, helix, and beyond were cut away and discarded. The remaining 16–18 mm length provided the material used for the complete occlusion condition. In order to create the partially occluded conditions, a portion of each ear canal impression was removed as described below.

Thresholds were repeated for each ear at octave frequencies (250–8000 Hz) and at half octaves (3,000 and 6,000 Hz) for each of the following four conditions (see Fig. 1):

1. Complete occlusion without the use of a lubricating seal ("100% w/o");
2. Complete occlusion with a thick layer of Otoferm cream applied to the surface of the ear mold impression to eliminate possible acoustic leakage ("100% w/");
3. With occlusion estimated to be between 60–80%. The remaining anterior portion of the impression was then cut horizontally to represent 60–80% occlusion ("60–80%");
4. With occlusion estimated to be between 40–60%. The remaining anterior portion of the impression was further cut horizontally to represent 40–60% occlusion ("40–60%").

Partial occlusion was determined using a template similar to one shown in Figure 1. Threshold differences between baseline (unoccluded) thresholds and each of the occluded conditions were calculated (shown in Table 1).

Table 1.   Mean Difference Scores in dB and Standard Deviations (SD) for Each of the Four Conditions (n = 10 ears)

	Frequency(Hz)								
	250	500	1000	2000	3000	4000	6000	8000	MEAN
100% with lubricant									
Mean	30	37	38	43	49	46	55	52	43.8
SD	10.6	8.2	7.5	8.3	5.8	7.6	2.7	5.5	
100% without lubricant									
Mean	19	22	25	33	34	35	37	33	29.8
SD	6.0	9.3	5.1	4.3	5.6	6.1	7.1	6.6	
60–80% occlusion									
Mean	8	4	8	15	20	18	15	16	13.0
SD	4.6	5.4	5.7	6.4	2.2	3.6	7.4	6.6	
40–60% occlusion									
Mean	3	3	4	8	12	12	9	9	7.5
SD	2.7	2.2	6.6	5.1	4.5	3.1	5.5	3.8	

Table 2. Duncan's Multiple Range Test for Ear Canal Occlusion Conditions (N = 45)

	Ear Canal Occlusion Condition			
	100% w/	100% w/out	60–80%	40–60%
Mean	43.76	30.31	12.71	7.00
Duncan Grouping	A	B	C	D

Note: Alpha set at 0.05, df 24.

All testing was performed in a double-walled, commercially engineered (Industrial Acoustics Corporation) sound room. Thresholds were obtained with a diagnostic audiometer (GSI, Model 61) calibrated according to American National Standards Institute (1996) with circumaural earphone cushions (Grason Stadler, with Telephonics TDH 50P drivers). The circumaural cushions were required to allow for adequate space between the diaphragm of the earphone driver and the occluding material in the ear canal.
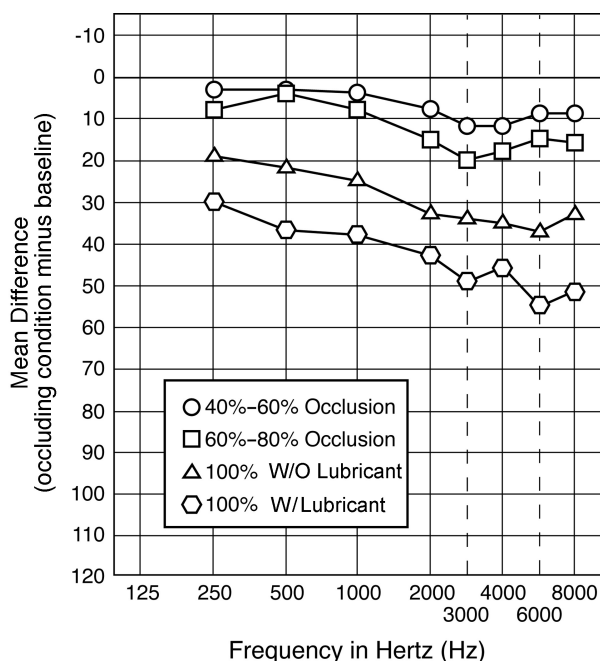
RESULTS

A comparison of thresholds between ears revealed not only mean differences between occluding conditions (100% w/, 100% w/o, 60–80%, and 40–60%) but also across

Figure 2. Mean threshold differences between baseline (unoccluded) tests and each occluded condition (complete occlusion with [w/] and without [w/o] Otoferm lubricant and with 40–60% and 60–80% occlusion; n = 10 ears).

frequencies for each condition. Between ear differences for the four conditions were 2.8, 1.6, .2, and 1.7 dB, respectively. Statistical analysis with a paired Student's t-test revealed no significant mean threshold differences between ears (t = 0.0307; p = 0.76), which allowed the data for the two ears to be pooled.

Table 1 provides mean threshold differences and standard deviations between baseline thresholds and the four occluded conditions for all ten ears and each test frequency; mean differences are presented in Figure 2. In general, mean threshold differences across frequencies varied by as much as 55 dB (100% w/ at 6000 Hz) to as little as 3 dB (40–60% at 250 Hz). As expected, the overall mean threshold differences increased as the degree of occlusion increased. With the exception of 100% w/ at 250 Hz, the standard deviation for all conditions by frequency were within 10 dB (see Table 1). For complete occlusion, the average shift across frequency was 43.8 dB with lubricant and 29.8 dB without lubricant. The use of the lubricant provided 14.0 dB of additional attenuation.

Of particular importance are the findings obtained in the partially occluded conditions. In the 40–60% and 60–80% occluded conditions, mean threshold differences across frequency were 7.5 dB and 13.0 dB, respectively (Table 1). A two-way ANOVA revealed a significant effect by condition of ear canal occlusion (F = 160.01, p < 0.0001), by frequency (F = 13.23, p < 0.0001), and a significant interaction between ear canal occlusion condition and frequency (F = 44.51, p < 0.0001). When collapsing all frequency data for each condition (see Table 2), the Duncan's Multiple Range Test post hoc analysis used to account for multiple comparisons suggested that each occlusion condition was significantly different (p < 0.05).

Although threshold differences across frequency between the unoccluded and occluded conditions for the least occluded

Table 3.   Duncan's Multiple Range Test for Frequency (N = 20)

	Frequency (Hz)							
	250	500	1000	2000	3000	4000	6000	8000
Mean	15.15	16.50	19.00	26.60	29.20	28.05	29.00	27.45
Duncan Grouping	D	D	D/C	A/B	A	A	A	A

Note: Alpha set 0.05, df = 24.

condition (40–60%) was only 7.5 dB, it should be noted that for the frequencies above 1000 Hz, mean threshold differences ranged from 8.0–12.0 dB, with an average of 10.0 dB. In the 60–80% occluded condition across frequency, threshold difference ranged from 4 to 20 dB, and averaged 13.0 dB; above 1000 Hz the range was from 15 to 20 dB with an average of 16.8 dB. When collapsing all occlusion conditions data for each frequency (see Table 3), the Duncan's Multiple Range Test post hoc analysis used to account for multiple comparisons suggested significant differences between the low and high frequencies ($p < 0.05$).

DISCUSSION

This study measured the effect of ear canal occlusion, from 40–60% to complete, on pure-tone thresholds. Results showed a decrease in threshold sensitivity for all occluding conditions. Thresholds were affected across frequencies for the two completely occluded conditions, but for the partially occluded conditions, only thresholds above 1000 Hz were significantly affected.

Absolute real ear attenuation levels and the trend for an increase of real ear attenuation from the low to high frequencies in the completely occluded conditions found in the current study are in close agreement with published data from a number of other investigations (see Berger and Casali, 2000).

The large differences between thresholds with and without the use of lubricant in the completely occluded conditions suggest that an acoustic leak will occur without lubricant when using the type of material used in this study. Earmold impression material is not designed for optimal real ear attenuation, as evident by the differences without and with the use of lubrication. Using lubricant can effectively seal the ear canal against acoustic leakage, providing an added 14 dB average added attenuation across frequency. This finding confirms the need for personal hearing protection devices to have a complete seal in order to achieve maximum real ear attenuation.

Clearly, the greatest impact of occlusion was on frequencies from 2000 through 8000 Hz regardless of condition. However, when ear canal occlusion increased from partial to complete, a significant decrease in low-frequency threshold sensitivity was observed. Threshold differences between 250 and 1000 Hz increased from an average of 3.3 and 6.7 dB in the 40–60% and 60–80% occluded condition, respectively, to as great as 22.0 and 34.6 dB in the completely occluded condition with/out and with the lubricant, respectively. Chandler (1962) observed the same effect across frequency and further indicated that this significant change occurs between partial occlusion at 95% and complete occlusion.

As shown in Table 4, our findings are in

Table 4. Comparison of Mean Difference Scores in dB from the Current Study with Data from Chandler

	Frequency (Hz)						
	250	500	1000	2000	4000	8000	MEAN
100% occlusion Chandler (1964)	29	30	43	42	39	59	40.3
Current Study (with lubricant)	30	37	38	43	46	52	41.0
Difference	**-1**	**-7**	**+5**	**-1**	**-7**	**+7**	**-0.7**
80% occlusion Chandler (1964)	4	-2	1	13	14	20	8.3
60–80% occlusion Current Study	8	4	8	15	18	16	11.5
Difference	**-4**	**-6**	**-7**	**-2**	**-4**	**+4**	**-3.2**

close agreement with those reported by Chandler (1962) for the completely and 60–80% occluded conditions. Mean differences between the two studies across frequency in the completely occluded condition averaged 0.7 dB and in the (60)-80% occluded condition 3.2 dB. Recall that Chandler collected data from only two subjects, indicating that the occlusion effect on thresholds is reliable and robust.

The low-frequency attenuation observed only when the ear canal was completely occluded is consistent with remarks from patients who report sudden hearing loss due to complete occlusion from impacted cerumen. Such patients typically experience sudden perceptual change in hearing sensitivity, presumably occurring when the ear canal progresses from partial to complete occlusion. In the partially occluded condition, frequencies below 1000 Hz are not attenuated significantly, and speech recognition thresholds are not appreciably affected. Frequencies at and below 1000 Hz are attenuated significantly only when the ear canal becomes completely occluded, at which time a perceptual change in thresholds for speech is noted. The clinical implication of this observation would suggest that even though high-frequency thresholds are affected with partial ear canal occlusion, even at 80% and greater, patients are often unaware of the high-frequency threshold sensitivity shifts and typically will not seek treatment until the ear canal is completely occluded and speech frequencies are attenuated.

Our findings have significant implications for pure-tone threshold audiometry, particularly when serial tests are performed such as in industrial hearing conservation programs. The threshold shift across frequency with partial occlusion from 40–80% averaged from 7.5 dB to 13.0 dB. However, above 1000 Hz, shifts averaged between 10.0 dB to 16.8 dB. Current OSHA regulations for industrial hearing conservation programs require averaging thresholds at 2000, 3000, and 4000 Hz for determining a Standard Threshold Shift (STS). A difference equal to or greater than 10 dB between baseline and periodic testing is considered a significant STS; retesting and referral is required when the shifts are confirmed.

The threshold attenuation resulting from the occluding conditions used in this study could adversely affect outcomes for industrial hearing conservation programs. For example, when partial occlusion is present at the baseline test, thresholds will be decreased. During the periodic (annual) follow-up testing, the ear canal will either continue to be occluded or it will be clear. If the ear canal clears, responses to pure tones will improve due to elimination of the ear canal debris. Unfortunately, if the debris is cleared and the employee experiences a recordable threshold shift, the obtained pure-tone thresholds will underestimate the degree of the recordable hearing loss. Conversely, if the ear canal is clear at the baseline test and becomes occluded for the periodic test, threshold testing will be affected by the amount of attenuation due to the occluding debris, and the amount of hearing loss will be overestimated. In this case, an STS, unnecessary follow-up testing, and an unnecessary referral could result. In either case, our data show that the clinical decisions made from pure-tone tests when ears are partially occluded by 40% or more can be spurious, simply due to the presence of debris in the ear canal.

Proper otoscopic inspection of the ear canal prior to audiometric testing should identify occlusions. Ears found to be obstructed 40% or more should be cleared prior to testing, which would eliminate elevated thresholds resulting from the presence of ear canal debris. While otoscopy is an important preliminary step for all threshold assessment, there are particular implications for industrial hearing conservation programs and many other programs using serial pure-tone audiometric threshold tests.

An informal survey indicates that only between 20–25% of industrial hearing conservation programs in the Unites States include otoscopy as part of the routine protocol (J. Lankford, pers. comm., 2003). The Council for the Accreditation of Occupational Hearing Conservation training courses have initiated a process to include didactic material and practical experience with otoscopy as a component of the technical training programs, but the formal protocols have yet to be completed and adopted. Data from this study would urge the adoption of otoscopy as part of the standard test battery.

Results from this study strongly support the routine use of otoscopy to identify occluded ear canals as part of all pure-tone threshold audiometry. While otoscopy is based on

subjective observations from examiners (Roeser et al, 1977), proper training and supervised hands-on experience will improve practitioner skills. The American Speech-Language-Hearing Association (1991) suggests that formal education and training for those performing otoscopy should include knowledge of the anatomy, physiology, and pathophysiology of the pinna, outer ear, and tympanic membrane; knowledge of medical and postsurgical conditions; and supervised practice in the use of an otoscope.

The proper use of otoscopy prior to pure-tone threshold audiometry to identify occluded ear canals coupled with ear canal management will reduce pure-tone threshold variability and improve the validity of pure-tone threshold assessment. Ear canals found to be partially occluded by 40–60% or more should be cleaned prior to pure-tone threshold assessment. In industrial hearing conservation programs, effective otoscopy and removal of ear canal debris will also reduce over-referral for work-related STS. A possible added benefit is that experienced observers may identify pathological conditions of the ear, such as external otitis, perforations, and fungus that can be referred for medical follow-up and possible treatment.

In this study we assessed the amount of threshold shift resulting from occlusion varying from 40% to 60% and greater, using occluding material 14–16 mm in length. While our data indicate that these degrees of occlusion do, indeed, significantly affect thresholds, additional studies are needed to determine whether occlusions with materials having different characteristics would have similar effects.

REFERENCES

American National Standards Institute. (1996) *Specifications for Audiometers*. ANSI S3.6-1996. New York: American Standards Institute.

American Speech-Language Hearing Association. (1991) External auditory canal examination and cerumen management. *ASHA* 33(5):65–66.

Berger E, Casali JG. (2000) Hearing protection devices. In: Valente M, Hosford-Dunn HH, Roeser RJ, eds. *Audiology: Treatment*. New York: Thieme Medical Publishers, 669–689.

Bricco E. (1985) Impacted cerumen as a reason for failure in hearing conservation programs. *J Sch Health* 55:240–241.

Brister F, Fullwood HL, Ripp T, Blodgett C. (1986) Incidence of occlusion due to impacted cerumen among mentally retarded adolescents. *Am J Ment Defic* 91:302–304.

Carhart R, Jerger JF. (1959) Preferred method for clinical determination of pure-tone thresholds. *J Speech Hear Disord* 24:330–345.

Chandler JR. (1962) Partial occlusion of the external auditory meatus: its effect upon air and bone conduction hearing acuity. *Laryngoscope* 74:22–53.

Cooper SJ. (1985) Relationship of hearing protector type and prevalence of external auditory canal pathology. Paper presented at the American Speech and Hearing Association Conference, Las Vegas, NV.

Crandell CC, Roeser RJ. (1993) Incidence of excessive/impacted cerumen in individuals with mental retardation: a longitudinal investigation. *Am J Ment Retard* 97:568–574.

Dahle AJ, McCollister FP. (1986) Hearing and otologic disorders in children with Down syndrome. *Am J Ment Defic* 90:636–642.

Fulton RT, Griffin CS. (1967) Audiological-otological considerations with the mentally retarded. *Ment Retard* 51: 26–31.

Gleitman RM, Ballachanda BB, Goldstein DP. (1992) Incidence of cerumen impaction in the general adult population. *Hear J* 45:28–32.

Hopkinson NT. (1981) Prevalence of Middle Ear Disorders in Coal Miners. U.S. Department of Health and Human Services Report No. 81-101. Cincinnati, OH: U.S. Department of Health and Human Services.

Mahoney DF. (1987) One simple solution to hearing impairment. *Geriatr Nurs* 8:242–245.

Mahoney DF. (1993) Cerumen impaction: prevalence and detection in nursing homes. *J Gerontol Nurs* 19(4):23–30.

Nudo L. (1965) Comparison by age of audiological and otological findings in a state residential institution for the mentally retarded: a preliminary report. In: Lloyd L, Frisina R, eds. *Audiological Assessment of the Mentally Retarded: Proceedings of a National Conference*. Parsons, KS: Parsons State Hospital and Training Center, 137–177.

Perry ET. (1957) *The Human Ear Canal*. Springfield, IL: Charles C. Thomas.

Roche AF, Siervogel RM, Himes JH, Johnson DL. (1978) Longitudinal study of hearing in children: baseline data concerning auditory thresholds, noise exposure, and biological factors. *J Acoust Soc Am* 64:1593–1616.

Roeser RJ, Clark J. (2000) Pure tone tests. In: Roeser RJ, Valente M, Hosford-Dunn HH, eds. *Audiology: Diagnosis*. New York: Thieme Medical Publishers, 227–252.

Roeser RJ, Soh J, Dunckel DC, Adams R. (1977) Comparison of tympanometry and otoscopy in establishing pass/fail criteria. *J Am Audiol Soc* 3:20–25.

Ruby RR. (1986) Conductive hearing loss in the elderly. *J Otolaryngol* 15:245–247.