6-2017

Occlusion Effects in Various Testing Conditions Using Insert Earphones

Amanda M. DeSantolo
The Graduate Center, City University of New York

OCCLUSION EFFECTS IN VARIOUS TESTING CONDITIONS USING INSERT EARPHONES

by

AMANDA DESANTOLO

A capstone research project submitted to the Graduate Faculty in Audiology in partial fulfillment of the requirements for the degree of Doctor of Audiology, The City University of New York
2017

This manuscript has been read and accepted for the
Graduate Faculty in Audiology in satisfaction of the
Capstone project requirement for the degree of Au.D.

Adrienne Rubinstein, Ph.D.

______________________ ____

Date Faculty Mentor

John Preece, Ph.D.

______________________ ____

Date Executive Officer

THE CITY UNIVERSITY OF NEW YORK

ABSTRACT

OCCLUSION EFFECTS IN VARIOUS TESTING CONDITIONS USING INSERT EARPHONES

By

Amanda DeSantolo

Advisor: Professor Adrienne Rubinstein

The occlusion effect is a well-known phenomenon that can affect audiological testing. Sound energy that would typically escape is trapped when covering the ear(s) and reflected back toward the inner ear. This increases the intensity of the sound, resulting in the "appearance" of a more sensitive threshold. Many aspects of the occlusion effect have been well researched and understood, however there are still aspects that warrant further investigation, such as the degree of occlusion with insert earphones when using partial versus full insertion and whether one or both of the ears are occluded. A within-subject design (n=5) was utilized to measure the occlusion effect at 250-1000 Hz in a variety of different occlusion conditions of clinical relevance. Results revealed occlusion effects in all conditions for at least some participants , although they were greater with partial as compared to full insertion. Thus, results of the present study support the need to account for the occlusion effect prior to masking frequencies 250-1000 Hz in order to ensure sufficient noise in the non-test ear. There were no clinically significant differences in degree of occlusion when comparing one versus both ears This finding allows for a potentially time saving procedure of inserting both inserts into the ears after obtaining initial bone conduction thresholds, which would be more expedient in situations where masking for both ears is required.

Key Words: occlusion effect, bone conduction, insert earphones

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Background

During audiological testing, hearing thresholds are typically established both via air conduction and bone conduction. Air conduction thresholds, commonly obtained using either supra-aural headphones or insert earphones, provide information regarding degree of hearing loss, as the thresholds measured reflect the transmission of sound through the entire auditory pathway. Bone conduction thresholds are obtained using a bone oscillator, which is typically placed on either the mastoid process or the forehead. Hearing sensitivity levels obtained via bone conduction provide information regarding the type of hearing loss, as the bone-conducted sound causes the skull to vibrate, thereby transmitting the sound energy directly to the inner ear and creating movement of the basilar membrane. This process, termed *distortional bone conduction,* is the greatest contributor in the transmission of a bone-conducted signal.

Although bone conduction stimulation is generally thought to reflect cochlear function, via the above-described process, it has been well established that the outer and middle ears also contribute to the transmission of the signal, albeit to lesser degrees. The middle ear component, referred to as *inertial bone conduction,* describes how vibration of the skull due to a bone conducted signal causes movement of the ossicles (Tonndorf, 1966). This movement, specifically the footplate of the stapes in and out of the oval window, causes movement of the fluids within the cochlea, which further enhances the signal. Whereas the exact contribution of the ossicles is unknown, Stenfelt, Hato & Goode's (2002) investigation revealed that the inertial effect is not significant for frequencies less than 1000 Hz, noting that the ossicles move in phase and with equal magnitude of the bone for lower frequencies; for frequencies greater than the resonant frequency of the bone (approximately 1.5k Hz), the phase of the ossicles begin to lag the phase of the bone.

The third component, *osseotympanic bone conduction*, refers to the outer ear contribution (Tonndorf, 1966). The vibration of the skull creates a motion relative to the surrounding air, thus creating a sound pressure in the air, referred to as a radiated sound. A radiated sound is also created in the ear canal, as the movement of the canal walls creates a sound pressure in the air within the canal. The radiated sound in the canal then causes movement of the tympanic membrane and is transmitted to the cochlea similarly to an air-conducted sound, thus contributing to the bone conduction signal (Stenfelt & Goode, 2005). More specifically, the cartilaginous portion of the ear canal is the primary generator for the outer ear component of bone conduction stimulation. The cartilage and soft tissues of the canal are more compliant than bone, which make it more susceptible to the bone conduction stimulation at frequencies below the resonant frequency of the skull, thus contributing to stimulation of low frequency sounds during bone conduction (Stenfelt, Hato & Goode, 2003). Radiated sound produced during bone conduction stimulation becomes of importance during audiological testing, as masking procedures that require the non-test ear to be covered in order to deliver a noise stimulus can potentially cause an occlusion effect. The occlusion effect is a phenomenon which occurs when the ears are covered. Sound energy that would typically escape through the ear canal is trapped and reflected back toward the inner ear; this increases the intensity of the signal, resulting in the "appearance" of a more sensitive threshold. Without taking this intensity increase into account, a clinician can easily misrepresent the true bone-conduction results of a client.

With regard to degree of occlusion, it is well established that it varies as a function of frequency. Hood (1962) described the occlusion effect as being confined to the lower frequencies, vanishing by 2000 Hz. Tonndorf (1964) and Rinne (1855) (as cited in Khanna et al. 1976), described two separate mechanisms that contribute to the occlusion effect for low and mid frequencies, respectively. First, the opening of the ear canal acts as a high-pass filter. When the ear is occluded, the filter effect is lessened and low frequency sound pressure that would have otherwise escaped is now trapped; this is the main contributing factor for increase of low frequency sounds. Additionally, when the ear is covered, there is an overall decrease in the resonant frequency of the ear canal, which affects the transmission of mid-frequency sounds. This notion that the greatest occlusion occurs in the low frequencies and decreases as frequency of the sound increases has been supported by many more recent investigations (Fagelson & Martin, 1998; Dean & Martin, 2000; Margolis & Moore, 2011, Small & Stapells, 2003).

Actual values of the occlusion effect vary across studies as the occlusion effect due to a number of variables other than frequency of the stimulating tone. One such variable that has been well studied is the effect of transducer type on the occlusion effect: supra-aural headphones versus insert earphones, in particular. In general, greater occlusion effects have been found for supra-aural headphones as compared to insert earphones (Dean & Martin, 2000; Margolis & Moore, 2011). Khanna et al. (1976) attributed this to the fact that both inner ear and external ear components increase as the contact area between the head and transducer increases.

Additionally, placement of the bone oscillator is a factor has been considered regarding its impact on the occlusion effect. The two most common locations are forehead and mastoid placement of the bone oscillator. Fagelson & Martin (1998) found no significant difference in occlusion effect when using a forehead as compared to mastoid placement. More recently, however, Stenfelt & Reinfeldt (2007) demonstrated up to 10-15 dB greater occlusion using forehead stimulation as compared to mastoid stimulation. Edgerton & Klodd (1977) also reported greater occlusion effects when using forehead placement of the bone oscillator as compared to mastoid placement, as well as greater variability in results when using forehead placement. Although potential benefits of both forehead and mastoid placement have been reported (Dirks & Malmquist, 1969; Stenfelt & Reinfeldt, 2007; Fagelson & Martin, 1998), placing the bone vibrator on the mastoid is indisputably most commonly used in clinical settings today. Thus, as noted by Margolis & Stiepan (2012), bone oscillators being used clinically are currently typically calibrated using an artificial mastoid.

Thus, whereas many aspects of the occlusion effect have been well researched and understood, such as how the occlusion effect is affected by frequency and type of transducer used, and others are less relevant due to current clinical practice (placement of the oscillator), there are still aspects of the occlusion effect that warrant further investigation. The present study explored some unresolved issues relating to the occlusion effect that are of clinical importance.

Purpose

The purpose of the present study is to determine whether bone conduction hearing thresholds significantly differ in a variety of clinically relevant occlusion conditions towards the goal of establishing a recommended clinical protocol. Whereas the occlusion effect can artificially improve hearing sensitivity thresholds during bone conduction testing, it can lead to artificial air-bone gaps and misdiagnoses of conductive hearing loss that do not exist and overestimation of existing conductive component.

As discussed above, it has been well established that significant occlusion effects occur when using supra-aural headphones. However, the amount of occlusion caused by insert earphones is not as clear. While some studies found large occlusion effects, others report much smaller values. For example, Dean & Martin (2000) found mean occlusion effects as high as 17, 14, and 6 dB HL at frequencies of 250, 500, and 1000 Hz, respectively. Margolis & Moore (2011), on the other hand, found mean occlusion effects as low as 3.3, 4.2, and -0.8 dB HL at those frequencies. Methodological differences may be responsible, at least in part, for differences in the findings. The lack of agreement in the literature supports the need for further investigation of the issue.

Variation in the literature regarding the amount of the occlusion reported with insert earphones seems to be due, at least in part, to insertion depth of the earphones utilized in different studies. Reporting of insertion depths are inconsistent across studies, which makes comparing data difficult. Studies use various depths of insertion such as 7mm, 10mm, 11mm, 13mm, and 22mm, and describe the depth using various phrases such as shallow insertion, deep insertion, full insertion, and partial insertion (Stone et al., 2014; Stenfelt & Reinfeldt, 2007; Small & Stapells, 2003). Other studies do not specify it at all (Fagelson & Martin, 1998; Guerrero-Aranda et al, 2016). While it seems to be generally accepted that deeper insertion results in a lesser degree of occlusion (Dean & Martin, 2000; Margolis & Moore, 2011), lack of consistent terms in the literature create issues when trying to apply results to be utilized clinically, as well as when comparing results across studies. For the purpose of this study, two insertion depths will be analyzed: partial and full insertion. An insertion depth protocol similar to Margolis & Moore (2011) was utilized. For the partially occluded condition, approximately one half of the length of the insert phone was inserted into the ear. This condition was included as it represents what is often done clinically. For the fully inserted condition, the insert was inserted into the ear canal such that the lateral edge was flush with the ear canal opening which approximates the depth recommended by the manufacturer, yet is still comfortable for most clients.

Another issue which may contribute to different results in the literature is the manner in which the occlusion effect is measured and defined. Some investigations have defined the occlusion effect as the difference in SPL, measured with a probe tube, with the ear occluded versus unoccluded (Tsai et al., 2005; Stone et al., 2014), whereas other studies have looked at the difference in behavioral thresholds between the different conditions (Edgerton & Klodd, 1977; Dean & Martin, 2000; Small & Stapells, 2003). Further, some studies have looked at both in an effort to make comparisons (Goldstein & Hayes, 1965; Fagelson & Martin, 1998, Stenfelt & Reinfeldt, 2007; Margolis & Moore, 2011; Reinfeldt et al., 2013). Fagelson & Martin (1998) reported that a strong association exists between ear canal SPL and behavioral measurements of the occlusion effect, however they did not find an exact decibel-for-decibel change between the measurements. Goldstein & Hayes (1965) found that changes in sound pressure were greater than changes in threshold between unoccluded and occluded conditions; this is of importance, as there may indeed be significant occlusion occurring that can be measured objectively with a probe tube, but which may not, however, be clinically relevant. Therefore, this investigation solely defined the occlusion effect in terms of changes in behavioral threshold.

Another issue of clinical relevance is whether occluding one versus both ears impacts the amount of occlusion measured; both methods are currently being used clinically, in part depending on which type of transducer is being used. Studies regarding this issue have yielded variable results. Edgerton & Klodd (1977) found greater occlusion effects with bilateral occlusion as compared to unilateral occlusion when using supra-aural headphones. Small & Stapells (2003) who also analyzed one versus both ears occluded utilizing insert earphones, found significant differences in behavioral thresholds between the occlusion conditions at some frequencies (1000 Hz and 4000 Hz) but not at others (500 Hz and 2000 Hz). Whereas both of these studies did find some differences between unilateral and bilateral occlusion, the variable results may be in part due to different transducers utilized (supra-aural headphones versus insert earphones).

Further, there are methodological issues in both studies, which call into question the validity of the findings. In both studies, random methods were used for obtaining one-ear occlusion measurements (i.e. the contralateral ear was always occluded in Edgerton & Klodd's (1977) study and the left ear was always occluded in the Small & Stapells' (2003) study). Therefore, it was not clear whether the ear being tested in the one-ear condition was the one with the larger occlusion effect, which more likely would have been similar to the two-ear condition. Other studies examining occlusion effect for only the one-ear occluded condition introduced masking noise to the contralateral ear as a remedy to this issue (Margolis & Moore, 2011; Stenfelt & Reinfeldt, 2007); whereas this method is successful in isolating the ear that is being examined, it introduces the potential of central masking. Therefore, the present study will examine the occlusion effect for each ear individually. Whichever ear provides the greater occlusion, will be the data included in analysis for the one-ear occluded condition. Similar to previous investigations, comparisons will be made between a one-ear versus two-ears occluded condition.

In summary, the literature is not entirely consistent in terms of clinical protocol and the quantitative occlusion effect with insert earphones. Therefore, this study will investigate whether the degree of occlusion differs as a function of insertion depth, as it has been postulated that if the insert earphone is positioned toward the bony part of the canal, the occlusion effect would be minimized; and further, given this positioning, the occlusion effect would not impact hearing testing (Stenfelt & Goode, 2005). However, positioning the insert this deeply in the canal potentially creates a different problem, as it may be uncomfortable for the patient. For this reason, data has also been collected with the earphones only partially inserted, as this condition reflects what is often done clinically. The current investigation will explore whether occluded bone conduction thresholds significantly differ from unoccluded thresholds; and, if so, whether it makes a difference if the inserts were fully or only partially into the ear. Additionally, the study will further investigate whether one or both of the ears being occluded impacts the degree of occlusion measured. If clinical diagnoses do not change when obtaining bone conduction thresholds in the various conditions, this would be important for establishing a new, simplified clinical protocol, which can save a significant amount of test time: a benefit to the clinician and the patient. If diagnoses do change, the current protocol should remain and clinicians should be sure not to test bone conduction with ears occluded by insert earphones.

OBJECTIVES AND RESEARCH QUESTIONS

The purpose of this study is to determine whether bone conduction hearing thresholds significantly differ in a variety of clinically relevant occlusion conditions using insert earphones towards the goal of establishing a recommended clinical protocol.

The following research questions were addressed:

1. Do occluded bone conduction thresholds significantly differ clinically from unoccluded thresholds 250-1000 Hz?
2. Is degree of measured occlusion related to the depth of the insert earphone in the ear (i.e. partially versus fully inserted)?
3. Does having one versus both ears occluded impact the degree of occlusion measured?

Methods

Participants

Five adults served as participants (2 male, 3 female) ranging in age from 27 to 85 years, with the mean age 51.2 years, (sd. 22.9). Participants were recruited via flyers placed in the student lounge of the Audiology Department at the CUNY Graduate Center, as well as via word-of-mouth. Participation was voluntary and unpaid. Selection criteria included: volunteers between the ages of 18 and 85 years and hearing either within normal limits or with a sensorineural hearing loss based on air-bone gaps no greater than 10 dB, and no worse than moderate, at 250-1000 Hz. All participants denied recent middle ear infections; tympanometry and ipsilateral acoustic reflexes were performed to rule out further conductive pathology. The study design and all procedures performed were approved by The City University of New York Graduate Center (protocol number: 2016-0183).

Procedures

Data were collected in one 40-minute session from each participant at the Graduate Center Hearing Science Laboratory. Audiometric data were obtained using a GSI 61 audiometer calibrated according to professional standards for audiometric instrumentation in a sound treated booth. Air-conduction pure tone thresholds were obtained using ER3A insert earphones at octave frequencies, 250-1000 Hz. The ER3A earphones were coupled to the ears using either the adult size (13.0 mm diameter) or pediatric size (9.0 mm diameter) foam tips depending on the size of the ear canal. For all participants, there was no greater than 15 dB interaural differences in air conduction thresholds at each frequency. Following air conduction measurements, bone conduction thresholds were obtained at octave frequencies 250-1000 Hz in an unoccluded condition, with each ear occluded individually, and with both ears occluded (Table 1). Occluded thresholds were obtained first with both inserts fully inserted into the ears, followed by the left and right ear individually occluded. Then this procedure was repeated with both inserts partially inserted into the ears, followed by the individual left and right occluded measurements. Mastoid placement of the B-71 bone oscillator was utilized for all bone conduction measurements. Given that all participants had symmetrical hearing and it is widely accepted that there is minimal interaural attenuation for low to mid frequencies, the side on which the oscillator was placed was randomized across participants. A within-subject design was utilized. Descriptive data were calculated and used to establish the clinical relevance for any differences noted between the unoccluded condition and each of the occluded conditions.

Table 1: Summary of Occlusion Conditions

Occlusion Condition	Description
Unoccluded	Bone conduction measurements with both ears unoccluded
One-ear occluded: *Partial Insertion*	Bone conduction measurements obtained with each ear individually occluded using an insert earphone that was only halfway inserted into canal. Statistical analysis performed using data from ear that provided the greatest occlusion.
Both ears occluded: *Partial Insertion*	Bone conduction measurements were obtained with both ears occluded using insert earphones that were only halfway inserted into each canal.
One-ear occluded: *Full Insertion*	Bone conduction measurements obtained with each ear individually occluded using an insert earphone that fully inserted into canal such that lateral edge was flush with opening of canal. Statistical analysis performed using data from ear that provided the greatest occlusion.
Both ears occluded: *Full Insertion*	Bone conduction measurements obtained with both ears occluded using insert earphones that were fully inserted into canal such that lateral edge was flush with opening of canal.

RESULTS

Occlusion effects were obtained for five participants 250-1000 Hz in a variety of occlusion conditions relevant to audiological testing, as summarized in Table 1. Behavioral thresholds obtained for each participant in each occlusion condition as compared to unoccluded thresholds for each frequency tested are shown in Table 2. Results revealed differences in behavioral thresholds measured in occluded versus non-occluded conditions for at least some of the participants, regardless of insertion depth of the insert earphones. However, the shifts in threshold appeared greater for the partially occluded condition than the fully inserted conditions, overall. On the other hand, when analyzing the behavioral thresholds for the fully occluded conditions in comparison with the unoccluded measurements, the data revealed relatively small shifts in threshold from the unoccluded measurements, or in some cases, no shift at all. The largest threshold shift was 15 dB, measured at only 1000 Hz for participant #2. Given the small sample size, it is unclear if this slightly larger value would occur in the same proportion with more participants or is an outlier in the data. On the other hand, larger shifts in threshold occurred more commonly when the insert earphones were only partially inserted into the ear(s).

Table 2: Behavioral Thresholds (dB HL) 250-1000 Hz in all Occlusion Conditions

Frequency	Participant	Unoccluded	Full Insertion Right	Full Insertion Left	Full Insertion Both	Partial Right	Partial Left	Partial Both
250 Hz								
	1	20	20	20	20	15	15	15
	2	5	-5	-5	-5	-10	-10	-10
	3	35	35	35	35	35	30	35
	4	5	5	5	5	0	5	-10
	5	5	5	5	5	-5	-5	-5
500 Hz								

1	30	30	30	30	25	25	25
2	20	15	5	10	15	-5	0
3	50	45	45	45	40	50	40
4	20	15	20	15	5	15	-5
5	0	0	0	0	-5	-5	-5
1000 Hz							
1	30	30	30	25	25	30	30
2	10	5	0	5	-5	0	-5
3	50	50	40	40	50	35	35
4	10	5	5	5	-5	0	-10
5	5	0	0	0	0	-5	-5

Occlusion effects were derived by subtracting occluded behavioral thresholds from the unoccluded threshold at each frequency for each condition. Overall, the data support the notion that the degree of occlusion is related to depth of insertion (Table 3). Greater occlusion effects occurred with partial insertion as compared to full insertion, with mean occlusion effects of 11 dB (sd. 2) and 4 dB (sd. 1.7), respectively, when collapsed across frequency. Differences between full and partial occlusion conditions were apparent at each frequency measured 250-1000 Hz, irrespective of whether one or both ears were occluded, and for all participants.

Table 3: Occlusion Effect (dB) Measured 250-1000 Hz for One and Both Ear Occluded Conditions

		250 Hz		500 Hz		1000 Hz
			Partial Insertion			
One-Ear Occluded	m.	8.0	m.	12.0	m.	12.0
	sd.	4.5	sd.	8.4	sd.	4.5
Both Ears Occluded	m.	9.0	m.	13.0	m.	12
	sd.	6.5	sd.	9.1	sd.	7.6
			Full Insertion			
One- Ear Occluded	m.	2.0	m.	5.0	m.	5.0

	sd. 4.5	sd. 6.1	sd. 5.0
Both Ears Occluded	m. 2.0	m. 4.0	m. 6.0
	sd. 4.5	sd. 4.2	sd. 2.2

Additionally, there did not seem to be a significant clinical difference between having one versus both ears occluded, regardless of whether the inserts were partially or fully inserted. For the partial insertion results, there was on average 10.6 dB of occlusion measured in the one-ear occluded condition, versus 11.3 dB in the both-ears occluded condition, when collapsed across frequency. Similarly, for the fully inserted results, there was an average of 4 dB of occlusion for both the one and both-ear occluded conditions, when collapsed across frequency. When looking at each frequency separately, results revealed no more than a 1 dB difference when comparing the two conditions.

Discussion

The purpose of the current study was to determine whether hearing thresholds obtained via bone conduction significantly differ in a number of clinically relevant occlusion conditions. These findings have the potential to impact clinical protocols. If the occlusion effect is not significant in the occluded conditions, it will validate a clinical protocol that would avoid the need to calculate or account for an occlusion effect, thus reducing test time or adding unnecessary masking.

The results of the present investigation indicated that occlusion effects are more prevalent and larger when the insert is only partially inserted into the ear as compared to fully inserted, thus suggesting that occlusion effect is related to depth of insertion. This is reflected in our results, as mean occlusion effects were greater at all frequencies for all partially occluded conditions as compared to the fully occluded conditions, as depicted in Table 3. Overall, it seems the mean occlusion effects measured in the present study are similar to those reported by Margolis & Moore (2011), who used a combination of acoustic and psychoacoustic occlusion measurements, for partial and fully inserted earphones.

The current results corroborated those of Dean & Martin (2000), who similarly found greater occlusion with the inserts shallowly or only partially inserted as compared to when they were more deeply inserted; however, the results differ in the amount of occlusion found at 1000 Hz when the inserts were deeply inserted. Dean & Martin (2000) found a mean occlusion effect of 1 dB (+/- 3.7) for 1000 Hz, concluding that this is not significant and therefore is not necessary to be accounted for during masking procedures given the insert in the non-test ear is deeply inserted. The present results differed, as in our most comparable condition (full insertion, one ear occluded) we measured a greater occlusion effect of 5 dB (+/- 5) at 1000 Hz. However, it is possible that these differing results may be in part due to methodological differences; in the present study the one-ear occluded data was determined by measuring each ear individual and including the data for the ear that presented the greater occlusion, whereas Dean & Martin (2000) always occluded the contralateral ear, which was arbitrary based on which side the bone oscillator was placed. Their methodology used may have underestimated the true one-ear occlusion effect, if the ears chosen coincidentally had smaller occlusion effects.

For the purpose of understanding clinical implications and making recommendations, consideration of individual responses is also warranted in addition to the previously discussed averaged data. When examining the results for occluded conditions when the inserts were fully inserted into the ears, mean values appear relatively low in comparison to the partial insertion conditions; however, individual responses provide further insight. While some of the participants had minimal and/or no measurable occlusion effects at some frequencies in the fully inserted conditions, others did have occlusion effects that would impact testing if not accounted. This individual variability highlights the need to test for the occlusion effect, regardless of insertion depth of the earphone.

When taking into consideration both averaged data and individual responses, it can be concluded that occlusion effects with either the inserts partially or fully inserted are clinically significant in that they would impact masking procedures. If initial bone conduction testing were completed with the ear(s) occluded, regardless whether the insert(s) were partially or fully inserted, it is likely thresholds would be significantly altered such that it would appear there were significant air-bone gaps. This would create a scenario where it would be seemingly necessary to mask for either one or both of the ears in terms of bone conduction; not only is this unnecessarily time-consuming, it might also results in inaccurate findings. For example, if initial bone conduction testing were performed with the ear(s) occluded and a greater than 10 dB difference between initial bone conduction threshold and both air conduction threshold was obtained, it would be seemingly necessary to mask for one or both of the ears. If the masked bone conduction threshold for the first ear that was masked for shifted greater than 10 dB, the initial bone threshold would potentially be mistakenly assigned as the true threshold for the other ear, which may lead to a false identification of a conductive component in that ear. Therefore, based on the results of this investigation, one should not test initial bone conduction thresholds while having the insert earphone(s) occluding one or both of the ears.

An alternative and/or additional problem that may occur if the occlusion effect is not considered is insufficient masking noise in the non-test ear during masking procedures. This is important as failure to account of the occlusion effect may result in ineffective masking of the non-test ear, which may lead to false identification of a conductive hearing loss. Ideally, the occlusion effect should be determined at time of testing, as results of this study suggest individual variability.

Interestingly, having one ear occluded versus both ears did not make a significant difference, thus suggesting that there is not a cumulative effect between the ears. Rather it is the ear with the greatest amount of occlusion that is responding in a "both ears occluded" condition. This does differ from previous investigations discussed, which found differences in the degree of occlusion depending on whether one or both of the ears were occluded (Edgerton & Klodd, 1977, Small & Stapells, 2003). Since the previous studies did not consider the impact of the random choice of ear in the one-ear condition, differences between their results and the current study may be explained at least in part.

Additionally, although analysis of the degree of occlusion in relationship to frequency was not a direct question of this investigation, it can be noted that no clear relationship was found between the amount of occlusion measured and the frequency. This differs from other studies, which have found more occlusion at the lowest frequencies (Fagelson & Martin, 1998; Dean & Martin, 2000; Margolis & Moore, 2011, Small & Stapells, 2003). The current investigation revealed the smallest occlusion effects at 250 Hz, irrespective of whether the inserts were fully or partially inserted into the ear. However, due to the small sample size it is unclear whether the values measured at 250 Hz are in fact significantly lower/different than the other frequencies.

There were certain limitations of this investigation that should be considered when examining results. There were ceiling effects for two of the five participants in the partially occluded conditions. That is, the true extent of the occlusion effect could not be determined at certain frequencies because limits of the audiometer were reached. For example, a participant with an unoccluded bone conduction threshold of 0 dB HL at 250 Hz responded to a tone at -10 dB when the inserts in the occlusion conditions with the insert earphones partially inserted. The true occlusion effect could not be determined, as the least intense tone the audiometer could produce was -10 dBHL. In this case, it is possible that the mean occlusion effects present in Table 2 for the partially inserted conditions are underestimations of the true occlusion effect. Future investigations should consider this when setting inclusion criteria. Additionally, Rosenthal effects cannot be ruled out, as this was not a double-blinded study. Although it is not felt that results were biased in either direction, future investigations should have separate persons involved in data collection and analysis whenever possible.

CONCLUSIONS

Clinicians should be aware that when using insert earphones, it is possible to have considerable occlusion effects that need to be accounted for during audiological testing. Further, the results of this study suggest greater occlusion occurs when the earphone is not fully inserted into the ear; clinically, this translates into greater amount of masking noise required to efficiently mask the non-test ear. This should be considered, especially in circumstances when there is an increased likelihood of over-masking. In these cases, it would be important to ensure the insert phone is fully in the ear to reduce the need for additional noise.

In terms of testing protocols, clinicians should not test initial bone conduction with inserts in the ears, regardless of depth of insertion. The results of this study showed clinically significant mean occlusion effects 250-1000 Hz for all partially occluded conditions, making clear that if initial bone thresholds were obtained in these conductions, thresholds would likely be artificially elevated. With regard to the results for occlusion effects in the fully inserted conditions, there were overall smaller occlusion effects, with some participants having no occlusion effects at certain frequencies. However, due to individual variability of results as well as the small sample size in the current investigation, it would be premature to assume that one can avoid testing for the occlusion effect and be able to obtain valid results.

There may, however, be a more time efficient procedure to test for the occlusion effect in cases when masking is necessary for both ears. Once one establishes initial bone conduction thresholds, both inserts can be placed into the ears, and the occlusion effect can be measured with both ears occluded. Given that the present results suggest that the occlusion effect measured with both ears occluded represents whichever ear had the greater occlusion, the measured value can be added to each masking calculation without risk of insufficient noise. Additionally, since there is negligible interaural attenuation 250-1000 Hz, accurate masked results can be obtained regardless of which side the bone oscillator is placed. This can potentially be advantageous, as masking can be completed for each ear without having to change the test set-up, which would reduce test time.

The overall results of the present study are of value to the clinician, as the need to check for the occlusion effect is supported, even with fully inserted earphones. However, the difference in the amount of occlusion measured when the inserts are only partially versus fully inserted into the ear is highlighted, which has clinical implications in terms of the amount of masking noise that would be required. Further, given that essentially the same amount of occlusion was measured regardless whether one or both of the ears were occluded, the option to check for the occlusion effect with both of the inserts in, followed by masking for both of the ears, is a potentially time saving procedure that may be of value to the clinician in certain situations.

APPENDIX A

Participants wanted for an audiology research study

If you are between the ages of 18 and 85 and have normal hearing, suspected hearing loss, or known hearing loss, please consider participating in our study regarding hearing sensitivity levels. The testing entails one 45-minute session. All results will be kept confidential.

Please contact Amanda DeSantolo to organize a time to meet

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

PARTICIPATE IN A HEARING STUDY!
adesantolo@gradcenter.cuny.edu

APPENDIX B

DATA COLLECTION FORM

Participant Number _______ Age _________ Gender: Male / Female

1. **Immittance Testing**

Tympanometry

Left:	Right:
ECV:	ECV:
TPP:	TPP:
static admittance:	static admittance:

Ipsilateral Acoustic Reflexes

500 Hz-	500 Hz-
1000 Hz-	1000 Hz-
2000 Hz	2000 Hz-

2. **Review and sign consent form**
3. **Audiological Testing**

	250 Hz	**500 Hz**	**1000 Hz**
RIGHT AC			
LEFT AC			
BC Unoccluded			
BC Partial- Left Occ			
BC Partial-Right Occ			
BC Partial-Both Occ			
BC Full- Left Occ			
BC Full- Right Occ			
BC Full- Both Occ			

References

Dean, M. S., & Martin, F. N. (2000). Insert earphone depth and the occlusion effect. *American Journal of Audiology*, *9*(2), 131-134.

Dirks, D. D., & Malmquist, C. M. (1969). Comparison of frontal and mastoid bone-conduction thresholds in various conductive lesions. *Journal of Speech, Language, and Hearing Research*, *12*(4), 725-746.

Edgerton BJ, Klodd DA. (1977). Occlusion effect in bone conduction pure tone and speech audiometry. J Am Audiol Soc 2, 151-158.

Fagelson, M. A., & Martin, F. N. (1998). The occlusion effect and ear canal sound pressure level. *American journal of audiology*, *7*(2), 50-54.

Goldstein, D. P., & Hayes, C. S. (1965). The occlusion effect in bone conduction hearing. *Journal of Speech, Language, and Hearing Research*, *8*(2), 137-148.

Guerrero-Aranda, A., Mijares-Nodarse, E., Hernandez-Perez, H., & Torres-Fortuny, A. (2016). Confirmation of previous results of the occlusion effect through auditory steady-state responses in normal-hearing adults. *Indian Journal of Otology*, *22*(4), 231.

Khanna SM, Tonndort J, Queller J. (1976). Mechanical parameters of hearing by bone conduction. J Acoust Soc Am 60, 139-154.

Margolis, R. H., & Moore, B. C. (2011). AMTAS®: Automated method for testing auditory sensitivity: III. Sensorineural hearing loss and air-bone gaps.*International Journal of Audiology*, *50*(7), 440-447.

Margolis, R. H., & Stiepan, S. M. (2012). Acoustic method for calibration of audiometric bone vibrators. *The Journal of the Acoustical Society of America*, *131*(2), 1221–1225.

Small SA, Stapells D. (2003). Normal brief-tone bone-conduction behavioral thresholds using the B-71 transducer: Three occlusion conditions. J Am Acad Audiol 14, 556-562.

Stenfelt S, Wild T, Hato N, Goode RL. (2003). Factors contributing to bone conduction: The outer ear. J Acoust Soc Am 113, 902-913.

Stenfelt S., Goode, RL. (2005). Bone-conducted sound: Physiological and clinical aspects. Otol Neurotol 26, 1245-1261.

Stenfelt, S., Hato, N., & Goode, R. L. (2002). Factors contributing to bone conduction: the middle ear. *The Journal of the Acoustical Society of America*, *111*(2), 947-959.

Stenfelt, S, Reinfeldt S. (2007). A model of the occlusion effect with bone-conducted stimulation. Int J Audiol 46, 595-608.

Stone MA, Paul AM, Axon P, Moore BC. (2014). A technique for estimating the occlusion effect for frequencies below 125 Hz. Ear Hear 35, 49-55.

Tonndorf, J. (1966). Bone conduction. Studies in experimental animals. *Acta oto-laryngologica*, Suppl-213.

Reinfeldt, S., Stenfelt, S., Good, T., & Håkansson, B. (2007). Examination of bone-conducted transmission from sound field excitation measured by thresholds, ear-canal sound pressure, and skull vibrations. *The Journal of the Acoustical Society of America*, *121*(3), 1576-1587.

Reinfeldt, S., Stenfelt, S., & Håkansson, B. (2013). Estimation of bone conduction skull transmission by hearing thresholds and ear-canal sound pressure. *Hearing research*, *299*, 19-28.

Tsai V, Ostroff J, Korman M, Chen JM. (2005). Bone-conduction hearing and the occlusion effect in otosclerosis and normal controls. Otol Neurotol 26, 1138-1142.