

Subjective and Objective Measures of the Occlusion Effect for Open-Fit Hearing Aids

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The purpose of this study was to determine the degree of measured and self-rated occlusion effect for 3 open-fit hearing aids. Measured occlusion effect was calculated from occluded and unaided real-ear responses obtained while participants vocalized /i/. Self-ratings were acquired using an occlusion effect scale. Results demonstrated that open-fit devices differed in degree of measured and self-rated occlusion effect. Self-ratings of occlusion effect were moderately correlated with objective real-ear measures.

One of the challenges in successfully fitting clients with hearing aids is overcoming the occlusion effect. Clients with good low-frequency hearing may complain that when they wear hearing aids, their voice sounds “boomy” or “hollow” (Dillon, 2001; Grover & Martin, 1979). This effect can be a source of annoyance to the client and a reason for instrument rejection (Kochkin, 2000).

The occlusion effect is an enhancement of bone-conduction responses, specifically for frequencies below 1000 Hz, that occurs when the ear canal is covered or blocked (Pohlman & Kranz, 1926; Sanders & Hall, 1999; Stenfelt, Wild, Hato, & Goode, 2003). The ear canal is bounded by the eardrum and walls of the canal. When the external ear canal is open, the canal acts as a high-pass filter, attenuating low-frequency sound energy. When an earmold or a hearing aid shell is placed in the external ear, it forms a fourth wall, occluding the canal and eliminating this filter (Dillon, 2001). As a result, when the cartilaginous and bony

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walls of the canal, as well as the mandible, are sent into vibration, this generates an increase in sound pressure at frequencies below 1000 Hz that results in the subjectively-reported hollow sound (Goldstein & Hayes, 1965; Kuk & Ludvigsen, 2002; Tonndorf, 1968). The occlusion effect has been reported to be as great as 15-25 dB sound pressure level (SPL) at 250, 500, and 1000 Hz (Fagelson & Martin, 1998; Goldstein & Hayes, 1965; Kuk & Keenan, 2006; Mueller & Bright, 1996; Westermann, 1987; Wimmer, 1986).

Open-Fit Hearing Aids

An open-fit approach can be used to increase satisfaction with hearing aids for clients that experience the occlusion effect (Revit, 1992). Both increasing vent size and decreasing the mass of the hearing aid inside the canal have been shown to minimize the occlusion effect. As the dimensions of vents are increased in an earmold or hearing aid, there is a decrease in the low-frequency SPL observed during real-ear measures of the occlusion effect (Dillon, 2001; Grover & Martin, 1979; Kiessling, Brenner, Jespersen, Groth, & Jensen, 2005; Kuk, Keenan, Lau, Dinulescu, et al., 2005). It should be noted that current hearing aids may also utilize digital signal processing algorithms or deep canal fittings to reduce the experience of the occlusion effect.

More recently, open-fit hearing aids that do not use a conventional vent have been introduced. These devices are behind-the-ear (BTE) hearing aids coupled to a silicone eartip that allows for retention, but does not occlude the canal. These open-fit hearing aids are designed to be acoustically transparent in the ear canal (Kiessling, Margolf-Hackl, Geller, & Olsen, 2003). Open-fit hearing aids have been found to be effective in attenuating low-frequency sounds. For example, it has been reported that the soft-silicone eartip provides a non-occluding fitting which mirrors a totally open real-ear unaided response (Kiessling et al., 2005; Kuk & Keenan, 2006; Kuk, Keenan, & Ludvigsen, 2005).

A client's perception of the occlusion effect is of equal or greater importance than the objective measurement of occlusion effect, because the client's subjective impression ultimately influences their satisfaction with the device. Subjective occlusion effect ratings have been obtained by asking participants to report comfort levels (MacKenzie, Browning, & McClymont, 1989). Using a rating scale, participants self-rated the "hollowness" or "naturalness of own voice" after reading phrases or passages aloud while wearing an earmold or hearing aid. Results have demonstrated that subjective ratings improve upon increasing vent size or decreasing the acoustic mass of the hearing aid (Kiessling et al., 2005; Kuk, 1991; Kuk, Keenan, & Lau, 2005; Kuk, Keenan, Lau, Dinulescu, et al., 2005; MacKenzie et al., 1989).

It would seem reasonable that objective and subjective measures of the occlusion effect should be correlated because larger vents result in a reduction in measured occlusion and better self-reports of voice acceptability. Research regarding

the relationship between these measures is equivocal. One study suggested there is no relationship between objective and perceived occlusion effect measures for individuals with hearing loss (Biering-Sorensen, Pedersen, & Parving, 1994). However, it has been reported that subjective ratings of sound quality may be more consistent for normal-hearing participants than for hearing-impaired participants (Grover & Martin, 1979). On the other hand, studies have reported positive correlations between the subjective reports of occlusion effect and measured occlusion effect, with good test-retest reliability for both hearing-impaired and normal-hearing individuals (Dillon, 2001; Kiessling et al., 2005; Kuk, Keenan, & Lau, 2005). These results, however, may be difficult to interpret. For instance, Kiessling et al. (2005) reported that probe-microphone objective measures explained less than 50% of the variation in perceived ratings of voice naturalness after reading a text sample orally. In addition, subjective ratings of hollowness have been only moderately correlated to probe-microphone measures of occlusion effect (Kuk, Keenan, & Lau, 2005). As a result, the relationship between objective and subjective occlusion effect has not been consistently established.

Purpose

The occlusion effect has been studied using earmolds with different venting schemes (Grover & Martin, 1979; Kiessling et al., 2005; Kuk, 1991; Kuk, Keenan, & Lau, 2005) and using specific open-fit devices (Kiessling et al., 2005; Kiessling et al., 2003; Kuk, Keenan, & Ludvigsen, 2005; Yanz & Olsen, 2006). There are currently a number of new products that attempt to minimize the occlusion effect. The degree of measured and perceived occlusion effect reduction for these newly marketed open-fit hearing aids has not been investigated thoroughly and the devices have not been directly compared to one another. Therefore, the purposes of this study were to determine: (a) the degree of occlusion effect for hearing aids with open-fit characteristics, (b) the degree of perceived occlusion effect for each device measured by a subjective occlusion effect scale, and (c) the correlation of objective and subjective measures of occlusion effect.

METHODS

Participants

Thirty young-adult participants, 20 females and 10 males, were recruited from the University of Connecticut student body. Participant mean age was 23.0 years (*SD* 3.0). All participants had normal hearing, 20 dB HL or better, bilaterally for octave frequencies between 250 and 8000 Hz. Otoscopic evaluations confirmed they had normal-appearing external ear canals and tympanic membranes bilaterally. Tympanometry screenings were completed using the GSI TympStar to rule out middle ear pathology. In order to be enrolled, participants had to have ear

canals larger than 0.230 in., as measured horizontally across the aperture of the canal from the anterior to posterior walls, and larger than 0.275 in., as measured vertically at the aperture of the canal from superior to inferior walls. Canal size was determined using a sizing mold of these dimensions that needed to be flush with the canal in order for the participants to be enrolled.

Hearing Aids

Three occlusion-minimizing open-fit hearing aids were used in this study: Oticon Open Ear Acoustics Adapto, General Hearing Instruments (GHI) Completely Open Ear (COE), and the Vivatone M44. The Adapto hearing aid uses a large vent accompanied by digital processing algorithms to eliminate occlusion. The COE device occupies approximately 50% of the ear canal to provide a comfortable and non-occluding fit. The Adapto and COE devices are in-the-ear (ITE) devices that were custom made for each participant. The M44 is a BTE hearing aid that is coupled to the ear canal by thin tubing which houses a connection from the aid to the receiver (Receiver Link). The receiver of the hearing aid is the only part of the device that is placed in the canal. There are three different size Receiver Links that were fitted for each participant on the day of testing. These three open-fit devices were chosen because of their unique methods of minimizing the occlusion effect. Both custom hearing aids used for this study were non-functional and consisted of only an outer shell, receiver, and battery door. Dead batteries were placed in each device during testing to approximate the weight of functional hearing aids.

Procedure

Data were obtained over three sessions. During Session 1, two sets of right and left ear impressions were made for each participant. In order to obtain deep ear canal impressions, foam otoblocks were placed past the second bend with an otolight. Impressions were made using medical grade two-part silicone. The impressions were sent to the manufacturer for open-fit custom shells constructed according to the device guidelines.

During Session 2, objective and subjective occlusion effects were measured for each device. Prior to testing, participants were provided with an information sheet on the occlusion effect that defined the phenomenon. They were asked to simulate the occlusion effect by vocalizing /i/ loudly and occluding both ears with their fingers. As they said /i/ they removed their fingers slowly and described what they heard to the researcher.

Each person was asked to remain as still as possible and place his/her head on a chin rest to keep it stable during data collection. The Fonix 7000 Quick Probe Real Ear Measurement System was used to obtain real-ear responses in a sound-treated booth. Each participant wore a headband with the reference microphone above the left pinna. The Fonix probe microphone was held at the ear by an ear

hook. The probe microphone was placed approximately 30 mm inside each person's left external ear canal, with the marker placed at the tragus. Otoscopic evaluations were performed to minimize the likelihood of probe-tube occlusion by cerumen or canal walls. The probe tube was taped to each participant's lobule to prevent probe movement upon hearing aid placement and removal. To assure that probe placement remained consistent following shell insertion and removal, a baseline real-ear unaided response (REUR) was obtained using a composite signal at 80 dB SPL. REURs were measured prior to the insertion of each device and compared to the baseline measure.

Objective REURs and real-ear occluded responses (REORs) were obtained for each hearing aid condition. Using a method similar to that described by Revit (1992), real-ear recordings were made with the Fonix 7000 signal source off. Participants were instructed to vocalize /i/ for 5 s at constant intensity level of 70 dB SPL-C as displayed on a Radio Shack 7-Range Analog Display Sound-Level Meter (Model #33-4050). The sound-level meter was placed 18 in. in front of participants at chin-rest level and set to "fast." First the REUR was obtained during vocalization (REURvoc). Then, to obtain a REOR during vocalization (REORvoc), a hearing aid was placed in the left ear only. Researchers also obtained test/retest curves for REURvoc and REORvoc to assure that the participants were vocalizing at approximately the same intensity level and pitch throughout testing. All real-ear response curves for each hearing aid and participant were captured from the Fonix 7000 and stored utilizing WinChap version 2.70 software. The real-ear occlusion effect (REOE) was calculated for frequencies between 200-1000 Hz by subtracting the dB SPL values for REURvoc from the values for REORvoc ($REORvoc - REURvoc = REOE$).

Participants also subjectively rated the degree of occlusion they experienced when the non-functional hearing aids were placed in both ears. First, they vocalized /i/ for 5 s unaided at 70 dB SPL-C as measured by the sound-level meter. They then repeated the same vocalization while wearing binaural non-functional hearing aids. Afterward, they rated the degree of occlusion effect based on the Occlusion Effect Scale displayed in Table 1. Participants returned for a third ses-

Table 1
Subjective Occlusion Rating Scale

Rating number	Rating meaning
0	No occlusion
1	Mild occlusion
2	Moderate occlusion
3	Severe occlusion
4	Complete occlusion

sion to repeat this subjective protocol.

Participants completed both objective and subjective procedures with each hearing aid and two repeated hearing aids (five conditions). Hearing aid order was randomized across subjects. Participants were not allowed to view the hearing aids until after all testing was complete to reduce bias based on visual appearance.

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), Version 14.0. Repeated measures analysis of variance (R-ANOVAs) statistics were performed to analyze differences in REOE based on hearing aid condition, frequency response, and an interaction between hearing aid and frequency response. R-ANOVA statistics and paired *t*-tests were completed to compare differences in subjective ratings based on hearing aid condition. Pearson correlation coefficients were obtained to determine if objective and subjective results reached statistical significance. Test/retest reliability of the objective and subjective measures was also analyzed.

RESULTS

Objective Occlusion

Mean REOEs were calculated for each hearing aid at 100-Hz intervals from 200 through 1000 Hz and are displayed in Figure 1. These frequencies were chosen because the occlusion effect is a low-frequency phenomenon and because the Fonix analyzer produces data at 100-Hz intervals only (Pohlman & Kranz, 1926; Sanders & Hall, 1999; Stenfelt et al., 2003). The Adapto had the greatest measured REOEs and largest standard deviations for all frequencies. The M44 and COE devices had minimal mean REOEs (below 2-3 dB SPL on average) from 200 through 500 Hz. REOEs for the M44 were minimal from 600 through 1000 Hz, but the COE had an increase in measured occlusion effect of up to 8 dB in that range.

An R-ANOVA was performed to establish whether hearing aid (Adapto vs. COE vs. M44), frequency (200 through 1000 Hz), and interaction of hearing aid and frequency resulted in statistically significant differences in REOEs. According to the results from the Huynh-Feldt test of within-subject effects, the interaction between hearing aid and frequency was statistically significant $F(16, 464) = 5.53, p = .00$. This implied that the highest and lowest REOE measures differed by frequency for each hearing aid. However, the bar graph of the mean data displayed in Figure 1 suggested that the interaction was ordinal because the mean data for all three hearing aids followed a similar trend in which occlusion effect measures increased between 500 and 900 Hz.

As a result, the main effects of hearing aid and frequency were analyzed. The R-ANOVA Huynh-Feldt test of within-subjects effects demonstrated a significant difference among hearing aids for REOEs measured at 200 through 1000 Hz,

$F(2, 58) = 33.45, p = .00$. Statistically significant differences in measured occlusion effect were also found among the frequencies tested (200 through 1000 Hz, in 100 Hz intervals), $F(8, 232) = 17.40, p = .00$, suggesting that measured occlusion effect differed across the frequency range.

Paired *t*-test comparisons of mean REOEs for each hearing aid were performed at 300, 500, 700, and 900 Hz. Paired *t*-tests were only performed at these frequencies to reduce Type I error. Comparisons of mean REOEs demonstrated that the results for the Adapto were significantly different from the COE and M44 de-

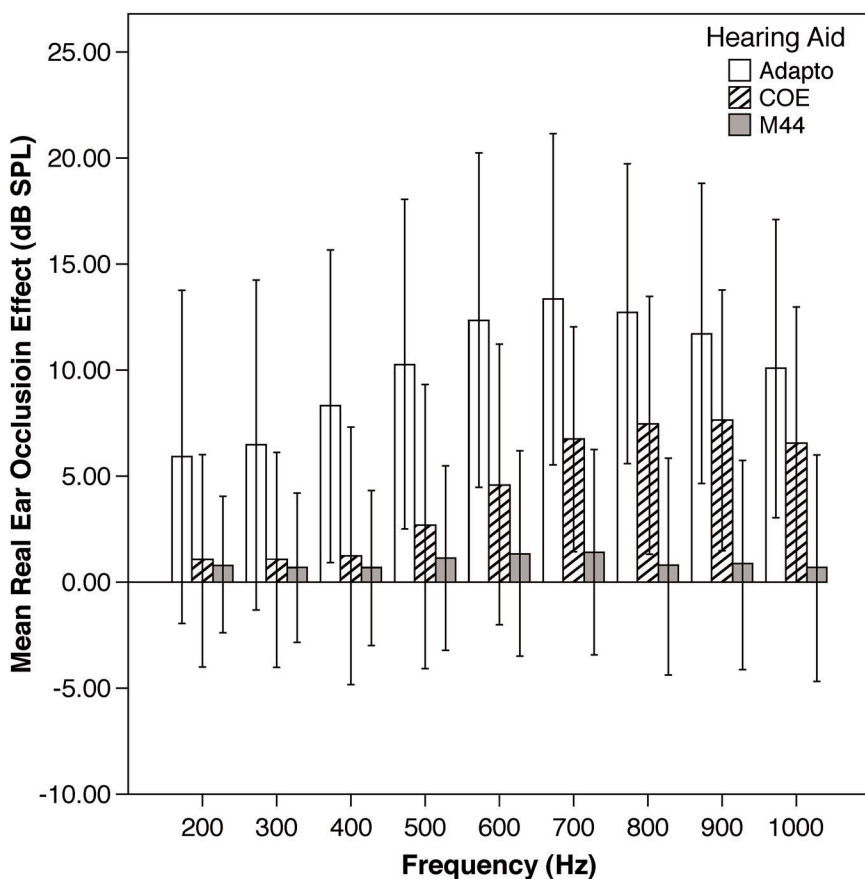


Figure 1. Mean real ear occlusion effect for three open-fit hearing aids for 100 Hz frequency intervals from 200 through 1000 Hz. Error bars represent plus and minus one standard deviation. Note. Adapto = Oticon Open Ear Acoustics Adapto. COE = General Hearing Instruments Completely Open Ear. M44 = Vivatone M44.

vices for 300, 500, and 700 Hz at the specified Bonferonni corrected significance level, $p < .004$. At 900 Hz, the M44 differed significantly from the Adapto ($p < .004$), but the COE did not. Mean REOEs for the COE and M44 devices differed significantly only at 900 Hz, $p < .004$. These results confirm that the Adapto had significantly greater measured occlusion than the other two devices for all frequencies analyzed, except for 900 Hz. The M44 and COE devices both had minimally measured occlusion at 300, 500, and 700 Hz; however, the COE device REOE measures were significantly greater than the M44 at 900 Hz.

Subjective Occlusion

Mean subjective ratings for the three hearing aids are displayed in Figure 2. Results demonstrated that the mean occlusion effect rating was between moderate and severe (2.43) for the Adapto, between mild and moderate (1.23) for the

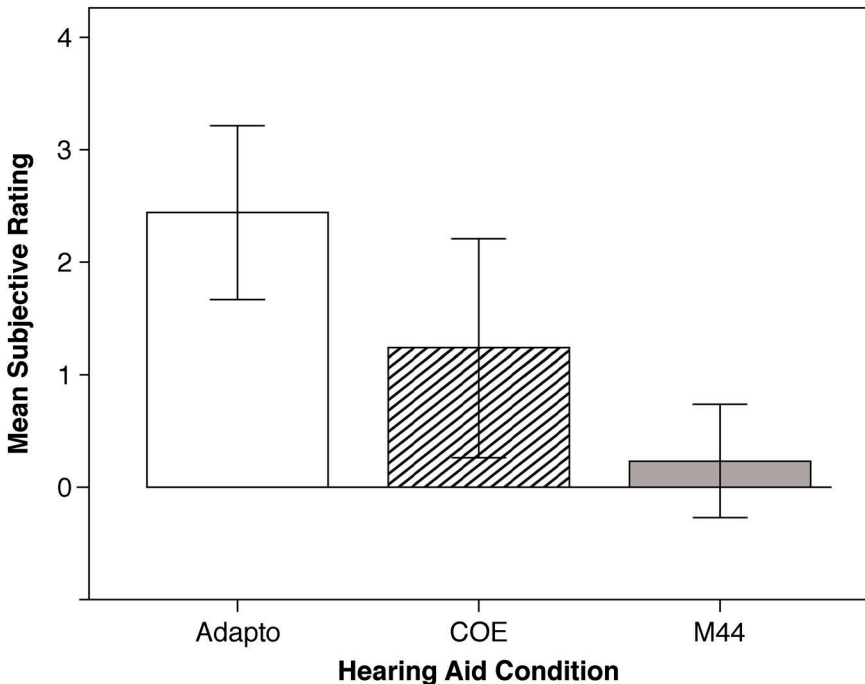


Figure 2. Mean subjective ratings for three open-fit devices. 0 represents no occlusion, 1 represents mild occlusion, 2 represents moderate occlusion, 3 represents severe occlusion, and 4 represents complete occlusion. Error bars represent plus and minus one standard deviation. *Note.* Adapto = Oticon Open Ear Acoustics Adapto. COE = General Hearing Instruments Completely Open Ear. M44 = Vivatone M44.

COE, and between none and mild (0.23) for the M44. An R-ANOVA indicated that overall hearing aid condition was significantly related to subjective ratings of occlusion effect, $F(2, 58) = 70.68, p < .00$. Paired t -tests were performed to determine significant differences in mean subjective rating between each hearing aid condition. The t -tests indicated that the subjective ratings were statistically different for all three devices at the Bonferonni-corrected significance level, $p < .017$. The Adapto had the highest mean subjective rating and the M44 mean subjective rating was significantly lower in comparison to the other two devices. The COE had the greatest amount of variability.

Objective and Subjective Occlusion

Pearson correlation coefficients were obtained for subjective ratings of occlusion effect and measured occlusion effect (at 100-Hz intervals between 200 and 1000 Hz) for all hearing aids. Coefficients and significance values are displayed in Table 2. Subjective ratings of perceived occlusion effect were fairly weakly correlated to the objective measures at 200 and 300 Hz and were moderately correlated at 400 through 1000 Hz for the Adapto. All correlations from 400 through 1000 Hz were significant, $p < .01$. Correlation coefficients between objective and subjective measures for the COE and M44 devices were weak and not statistically significant.

It is important to note that the hearing aids were nonfunctional in this study. Therefore, it is possible that there may have been varying degrees of mid- and high-frequency insertion loss due to the hearing aid being placed in the ear canal. If insertion loss was significant, it is possible that this would have created a simulated hearing-impairment for participants. As a result, partial Pearson correlation coefficients were also obtained for subjective ratings and measured occlusion effect for each hearing aid with insertion loss entered as a control variable. Real-ear insertion loss measures (REIL) were available for each subject from a companion study in which REUR and REOR data were obtained using an 80 dB SPL Fonix composite signal. The same hearing aid conditions and same study procedure were used on the same day REOE data were collected. The REIL was calculated by subtracting the REUR values from the REOR values (REOR - REUR = REIL). The peak REIL value between 2000 and 4000 Hz was chosen for each hearing aid condition. These frequencies were evaluated because it has been shown that insertion loss occurs within this frequency range (Wang, 2004).

For both the COE and M44 devices, the partial correlations indicated that subjective ratings were not significantly correlated to objective measures of occlusion effect for 100-Hz intervals between 200 and 1000 Hz. The previously described significant correlations between subjective and objective measures for the Adapto device (see Table 2) remained significant following the inclusion of insertion loss as a partial correlate (see Table 3). The results suggested that participants' ratings of occlusion were not significantly influenced by insertion loss.

Table 2
Pearson Correlation Coefficients Between Measured Occlusion Effect (250-1000 Hz) and Subjective Ratings of Occlusion Effect by Frequency for Each Hearing Aid

	Objective occlusion effect								
	200	300	400	500	600	700	800	900	1000
Subjective Rating Adapto	.278 <i>p</i> = .14	.324 <i>p</i> = .08	.372 <i>p</i> = .04	.460* <i>p</i> = .01	.538* <i>p</i> = .00	.567* <i>p</i> = .00	.495* <i>p</i> = .01	.420* <i>p</i> = .02	.409* <i>p</i> = .03
Subjective Rating COE	-.029 <i>p</i> = .88	.007 <i>p</i> = .97	.064 <i>p</i> = .73	.050 <i>p</i> = .79	.073 <i>p</i> = .70	.049 <i>p</i> = .78	.038 <i>p</i> = .84	-.007 <i>p</i> = .97	.080 <i>p</i> = .68
Subjective Rating M44	-.229 <i>p</i> = .20	-.151 <i>p</i> = .43	.070 <i>p</i> = .71	.216 <i>p</i> = .25	.211 <i>p</i> = .27	.200 <i>p</i> = .29	.231 <i>p</i> = .22	.268 <i>p</i> = .15	.115 <i>p</i> = .55

Note. Adapto = Oticon Open Ear Acoustics Adapto hearing aid. COE = General Hearing Instruments Completely Open Ear hearing aid. M44 = Vivatone M44 hearing aid.

* Indicates a statistically significant correlation, *p* < .05.

Table 3
Partial Pearson Correlation Coefficients Between Measured Occlusion Effect and Subjective Ratings of Occlusion Effect by Frequency for the Adapto Device; Insertion Loss was the Control Variable

	Objective occlusion effect								
	200	300	400	500	600	700	800	900	1000
Subjective Rating Adapto	.281 <i>p</i> = .14	.327 <i>p</i> = .08	.387* <i>p</i> = .04	.481* <i>p</i> = .01	.554* <i>p</i> = .00	.579* <i>p</i> = .00	.510* <i>p</i> = .01	.454* <i>p</i> = .02	.442* <i>p</i> = .02

Note. Adapto = Oticon Open Ear Acoustics Adapto hearing aid.

* Indicates a statistically significant correlation, *p* < .05.

Test/Retest Reliability

Independent *t*-tests were used to compare differences in intra-session REURs, REOEs, and subjective ratings for each hearing aid. *t*-Tests were conducted for REURs at 100-Hz frequency intervals from 200 through 1000 Hz. The 95% confidence intervals for REURs in each hearing aid condition indicated that there was no significant difference in test-retest REURs. All 95% confidence intervals contained 0 and were not significant at the specified $p < .05$ level. This suggested that the probe microphone remained in the same position during the testing and the results were reliable. In addition, 95% confidence intervals were obtained for intra-session test-retest REURvoc data for each hearing aid condition. Independent *t*-tests revealed that all 95% confidence intervals contained 0 and were not significant at the specified $p < .05$ level, suggesting that each participant's voice pitch was stable during testing. Finally, test-retest variability for subjective self-ratings was analyzed using independent *t*-tests and 95% confidence intervals. Results indicated no significant differences between test-retest conditions for each hearing aid. Therefore, these results suggest that reliability for subjective rating measures between conditions was good.

DISCUSSION

The results indicated that the degree of measured occlusion effect varied among the different occlusion management strategies. The COE and M44 devices had significantly less measured occlusion effect in comparison to the Adapto device and the M44 demonstrated the lowest measured occlusion effect overall. Measured occlusion effect was the lowest for the device with receiver in-the-canal and highest for the largest ITE device. This is consistent with previous findings which indicated that hearing instruments that take up less space in the canal or use larger vents have less measured occlusion (Dillon, 2001; Grover & Martin, 1979; Kiessling et al., 2005; Kuk, Keenan, Lau, Dinulescu, et al., 2005). The average values for the M44 were not only minimal, but were within the 2 dB SPL immediate test-retest variability limits for real-ear measures (Mueller, Hawkins, & Northern, 1992). Therefore, the average occlusion measured for the M44 device could be the result of probe movement during testing more so than the occlusion effect. These results are similar to published results using similar open-fit devices (Kiessling et al., 2005; Kuk & Keenan, 2006; Kuk, Keenan, & Ludvigsen, 2005). Measured occlusion effect was the highest for the Adapto device. In Figure 1, individual measures of occlusion were measured as high as 20 dB for the Adapto. This is similar to the 20 to 25 dB of measured occlusion reported by Mueller et al. (1992) for standard earmolds. As a result, the Adapto shell did not successfully minimize occlusion. However, it must be noted that the Adapto device also relies on advanced signal processing to reduce the occlusion

effect while the hearing aid is in use and the hearing aids in this study were non-functional.

The differences observed between the COE and M44 devices above 600 Hz may have been the result of the area of the canal left open by the COE shell. It has been suggested that the occlusion effect is a function of vent characteristics and that as vent diameter increases, the peak frequency of measured occlusion increases (Kuk & Keenan, 2006). The COE strategy leaves 50% of the canal open; therefore, it is possible that due to the large amount of canal that is left open, peak measured occlusion is at a higher frequency than is observed for the Adapto device. In addition, the possible changes in peak frequency of occlusion also provide an explanation for why the results demonstrated a main effect of frequency in the R-ANOVA.

Subjective ratings suggested that the M44 had the least amount of perceived occlusion effect, with an average rating between no and mild occlusion effect. The COE device, on average, was rated to have mild to moderate perceived occlusion effect while the Adapto device average rating was between moderate to severe occlusion effect. These results are consistent with previous studies demonstrating that subjective ratings improve upon decreasing the acoustic mass of a hearing aid (Kiessling et al., 2005; Kuk, 1991; Kuk, Keenan, & Lau, 2005; Kuk, Keenan, Lau, Dinulescu, et al., 2005; MacKenzie et al., 1989). However, subjective ratings may be biased due to the perception of hearing aid shape within the ear canal. Even though participants were blinded to each hearing aid condition, the difference in device placement and weight could be felt physically. As a result, ratings of occlusion effect may have been biased by the perception of device size. This is an issue that should be addressed in future research.

The subjective and objective results were complementary; the M44 device had the least amount of measured and perceived occlusion, while the Adapto resulted in the highest ratings and objective measures of occlusion. However, these two measures were only weakly to moderately correlated. These results support previous research that has included correlations between subjective and objective measures of occlusion effect. Kiessling et al. (2005) found that measured occlusion effect explained about 46% of the variation of perceived occlusion. Kuk, Keenan, and Lau (2005) demonstrated weak to moderate correlation values even though there was a tendency for subjective ratings to improve as measured occlusion effect decreased. It is important to note that the mild to moderate correlation values were consistent across these studies, even though different subjective rating scales were used. The moderate correlation values indicate that subjective and objective measures may not always be consistent for patients and it has been suggested that the relationship between these two measures is not one-to-one (Kuk & Keenan, 2006). As a result, audiologists cannot depend solely on objective measures to provide information about patient's perception of the occlusion effect.

CONCLUSIONS

Overall the results of this study suggest that open-fit devices, such as the M44 and COE, are successful in reducing measured and perceived occlusion effect. Further, mild occlusion effect ratings were common for the devices that had less occupying space in the canal in comparison to moderate occlusion effect ratings for the larger ITE device. The moderate correlations between objective and subjective measures of occlusion effect suggest that it is important to consider the patient's subjective impression of occlusion during hearing aid fitting; a patient's subjective impression will ultimately affect their success with the hearing aid. To increase the face validity and clinical application of this research, further research should include participants with varying degrees of hearing loss and different types of functional hearing aids should be used. In addition, research comparing occlusion reduction strategies, such as open-fit versus digital signal processing, should be performed. This will help determine if physical changes to hearing aids are necessary for occlusion reduction or if digital signal processing alone is as effective.

In addition the real ear measures and self-ratings of occlusion effect used in this study had good intra-session and inter-session test-retest reliability. Based on these findings, they may be considered useful, repeatable measures of the occlusion effect in the clinical setting.

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