The vent effect in instant ear tips and its impact on the fitting of modern hearing aids

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Today, approximately 70-80% of hearing aid fittings are made with instant ear tips. This may be due to ease of fit, improved physical comfort and the reduction in occlusion compared to custom earmolds. These tips can be completely open, vented, or closed. The acoustic properties of the ear tip depend on its type, size and the fit to the individual ear canal. Depending on the resulting real ear occluded gain (REOG) and vent effect (VE), the sound quality and aided benefit provided by the hearing aid may vary among individuals fitted with the same ear tip type. This study explored five Widex instant ear tips both in relation to REOG and VE using real ear measurements on 60 ears and in relation to subjective occlusion ratings. The results showed a large variation in REOG and VE both between ear tips and across subjects within the same ear tip type, and a high correlation between VE and perceived occlusion. These results imply that the acoustics of instant tips need to be assessed and considered as part of the hearing aid fitting process to ensure that fitting targets are matched.

INTRODUCTION

Open-fit and receiver-in-the-canal (RIC) hearing aids (HAs) have emerged in the last decade and become very popular due to their attractive and comfortable-to-wear design (Hallenbeck and Groth, 2008). The strong preference for RIC devices might also be a result of the HA performance, especially with the improvement of feedback-cancellation algorithms (Martin, 2008) and extended frequency bandwidth (Kuk and Baekgaard, 2008) in comparison to behind-the-ear HAs. In the United States RIC-style HAs constituted 82.6% of the private sector market and 77.9% of veteran affairs (VA) dispensing, for a total of 81.7% of all HAs dispensed in the first half of 2019 (Hearing Review , 2019). With the increased number of RIC devices, the use of instant ear tips has grown proportionally, whereas the number of custom moulds has decreased. Instant ear tips have been reported to be used in about 70 % of the fittings (Smith, *et al.*, 2008; Sullivan, 2018). The preference for instant ear tips might be mostly due to two reasons: time efficiency and increased comfort. With instant HA fitting during the first visit to the hearing clinic and no need to take earmould impressions, more time can be spent on counselling, fine-tuning, and verification (Caporali *et al.*, 2013). Instant ear tips also generally provide more comfort and reduce the occlusion effect (Pohlman and Kranz, 1926; Dillon, 2012; Stenfelt *et al.*, 2003). They are available from all manufacturers in a variety of shapes and sizes, ranging from so-called open ear tips to closed tips that aim to completely occlude the ear canal.

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Ear tips may be designed to include vents, or they might allow for leakage between the tip and the ear canal wall, which leads to an increased but uncontrolled effective vent size.

Every ear tip has an acoustic effect on the sound pressure at the eardrum, both for sounds amplified by the HA, for sounds produced outside the ear canal, and for the mixing of the two sound sources at the eardrum. For sound amplified by the HA, increasing the effective vent size decreases the amount of low-frequency energy at the eardrum, which we refer to here as the vent effect (VE, e.g., Dillon, 2012; Kuk and Keenan, 2006; Kuk and Nordahn, 2006). For sounds generated outside the ear canal, increasing the effective vent of the ear tip increases the level of the direct sound at the eardrum, an effect described by the real ear occluded gain (REOG). If the transmitted sound and the sound played by the HA are similar in level, the superposition of the direct and the slightly delayed amplified sound results in a comb filter effect (Dillon, 2012; Mueller and Ricketts, 2006). If the direct sound is higher in level than the amplified sound at certain frequencies, this can render HA processing algorithms like beamformer or noise reduction less effective, because the direct sound dominates the perception (Keidser *et al.*, 2007).

For traditional vented custom moulds, these effects are well-understood and well-documented (Kuk and Nordahn, 2006). There has been some research on the acoustics of open fittings, reviewed in Winkler *et al.* (2016). For other instant ear tips, the literature is very sparse. Jespersen and Møller (2013) found that the reliability of the acoustic properties of instant tips and custom moulds was comparable, and Smith *et al.*, (2008) found that instant tips offered a viable assess-and-fit option in clinical practice. This lack of knowledge is especially problematic given the popularity of instant tips, because the understanding of ear tip acoustics is essential for making the right fitting choices for a given hearing loss, especially for patients with a mild hearing loss at low frequencies, who require a compensation of the VE in order to match the fitting target. Similarly, knowledge of the REOG of a specific ear tip is important, because it allows for adjustments of the HA gain to minimise comb filter effects.

This study aimed to provide acoustic reference data for five types of silicone instant ear tips ranging from open to closed (no intentional venting) and to look at the inter-subject variability across ear tips. Three research questions have been addressed: 1) What is the REOG for the five different ear tips across subjects? 2) What is the VE for the different tips and how much does it vary across subjects? and 3) How much occlusion do the test subjects experience with these ear tips and how does that relate to measured VE?

METHODS

Test subjects

Thirty normal-hearing subjects (10 female) participated in the experiment. The average age was 45 years (min. 19, max 67). All participants were employees of WS Audiology. The subjects were screened before the experiment to determine the ear tip size and wire length required to fit their ears. The selection criterion was to have a broad range of different sizes of ear canal and body heights and to include both genders. Before starting the experiment, they received written information about the experiment and gave informed consent to their participation and to the use of the resulting anonymised data for publication.

Procedure and apparatus

The main part of the experiment comprised a series of real-ear measurements using an Interacoustics Affinity 2.0 measurement system. The listeners were placed facing the system at a distance of 1 m in an acoustically dampened audiometric room. A pair of Widex Evoke 440 Passion receiver-in-the-canal (RIC) HAs with ‘S’ receivers was used for all measurements. They provided 10 dB linear gain in all 15 frequency channels. All adaptive processing was deactivated. The ear tips under investigation were Widex Open, Tulip, Round (2-vent), Round (1-vent), and Double-domes instant ear tips (cf. Fig. 1). The order of testing the different ear tips was counterbalanced across test subjects to avoid order effects.

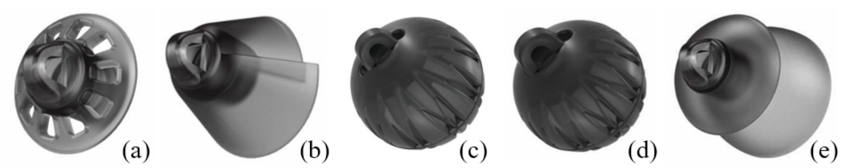

Fig. 1: Instant ear tips used in this study: Open (a), Tulip (b), Round (2-vent), c), Round (1-vent), d), Double domes (e)

After an initial otoscopic examination of the ear canal and the calibration of the probe microphones, the probe tubes were placed in the ear canals close to the eardrum and real-ear unaided responses (REUR) were measured using pink noise played back from the Affinity system at 0° azimuth at a distance of 1 m at a level of 65 dB SPL. Then the HAs were placed on the ears and the tips were inserted into the ear canal. Subsequently, real-ear occluded responses (REOR) were measured with the HAs switched off. The REOG was computed as the difference between the two measurements in dB (REOG = REOR – REUR).

The VE for each ear tip was obtained from a second pair of measurements. Brown noise was streamed to the HAs via a TV-DEX streaming device. Subsequently, the ear canal and the concha were filled completely with impression material with the receiver and ear tip still in place. This allowed for the measurement of a fully occluded response with no leakage. The VE was computed as the difference between the response measured in the ‘normal’ streaming measurement and the measurement with impression material.

Finally, the test subjects were asked to utter the names of the months of the year and rate the perceived occlusion based on the sound of their own voice on a scale ranging from 0 (no occlusion, “like normal listening”) to 10 (complete occlusion, “as if they stuck their fingers in their ears”).

RESULTS

Real ear occluded gain

The results for one test subject were excluded from the analysis due to issues with cerumen occluding the probe tube during some measurements. Fig. 2 shows the average REOG across the remaining 58 ears for the different ear tips (top left panel). The other panels show the same average REOG (thick line), +/- one standard deviation (shaded area), and the individual measurements (light grey lines) for each of the ear tips separately. The average results (top left) show that the Open ear tips are mostly transparent for sound generated outside the ear canal, apart from a slight attenuation of about 2 dB at mid- and high frequencies above about 2 kHz. The remaining tips form two groups with different gain responses. The Tulip, Round 1 and 2 tips show very similar attenuation patterns with a transparent response up to about 1 kHz and a maximum attenuation of about 9 (Tulip) to 12 dB (Round, 1-vent) at a frequency of about 2.6-2.8 kHz. Double domes are on average only transparent up to about 600 Hz, and they show the highest attenuation of 16 dB at 3 kHz. The data also show high variability between subjects across ear tips, which is largest for double domes.

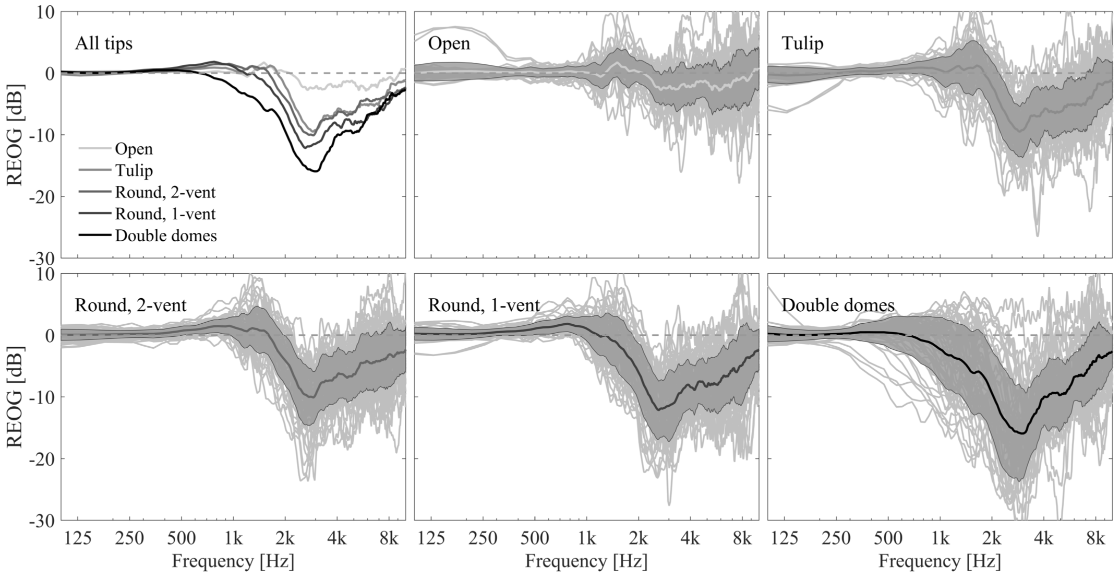

Fig. 2: Average REOG across 58 ears for the five ear tips (top left). The other panels show the average REOG per tip (thick line) and +/- 1 standard deviation (shaded area). The light grey lines represent individual measurements.

Vent effect

Fig. 3 shows the average VE across 58 ears for each of the tips (top left) and the average value (thick line) +/- one standard deviation (shaded area) and the individual measurements (light grey lines) for each tip separately. On average, the largest VE was found for open tips. Here, the vent loss starts just below 2 kHz and reaches a maximum of about 40 dB around 125 Hz. Noteworthy is also the peak in the VE curve between about 2 and 6 kHz. This peak is caused by the difference in the magnitude of the ear canal resonance between the two underlying measurements. While the Open tip hardly affects the natural ear canal resonance at all, its magnitude is clearly reduced when the impression material is inserted. Tulip, Round (2-vent) and Round (1-vent) show very similar responses with a vent loss starting between 1 and 1.5 kHz and a maximum attenuation of about 30 dB at the lowest frequencies. Double domes show the least pronounced vent loss with a cut-off frequency of about 1150 Hz and an average VE of 24 dB around 125 Hz. There is also a high variability in the VE measurements across ear tips. Open shows the lowest and Double domes show the highest variability, which also was seen for the REOG. At the lowest frequencies, the VE with Double domes might be as low as 6 dB (nearly fully closed) or as high as 38 dB (nearly completely open).

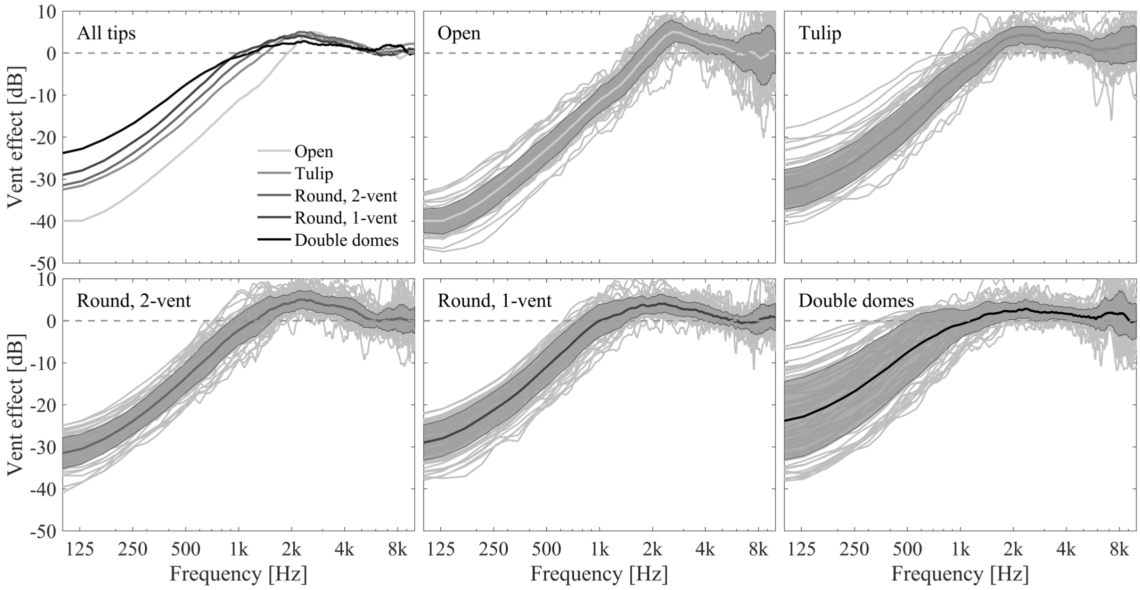

Fig. 3: VE, averaged across 58 ears for each ear tip (top left). The other panels show the average VE per tip (thick line) and +/- 1 standard deviation (shaded area). The light grey lines represent individual measurements.

Occlusion ratings

Fig. 4 shows the average occlusion ratings for the different ear tips (open circles) +/- one standard deviation and for the condition with impression material (filled circles). The smaller grey symbols represent individual responses. Circles indicate that the occlusion was perceived equally strong on both ears. Triangles point in the direction of the ear with higher occlusion. On average, open tips were perceived as least occluding with an average rating of 0.82, followed by Tulip (2.31), Round 2 (2.87), Round 1 (3.23), and Double domes (3.74). The individual ratings showed a trend of increased variability with increasing average occlusion rating. Whereas all ratings for Open tips were rated between 0 and 4, the ratings for Double spread from 0 to 8.

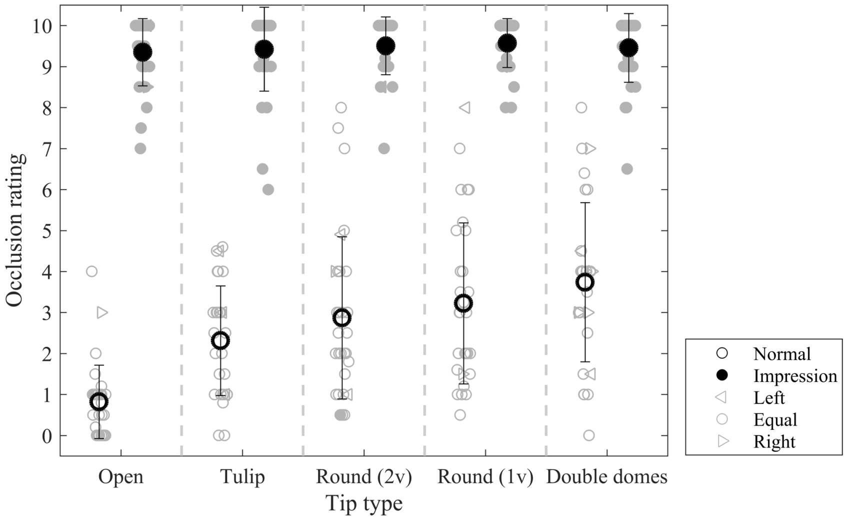

Fig. 4: Individual occlusion ratings (grey) and mean +/- one standard deviation (black). Circles indicate equal amounts of occlusion on both ears, triangles point in the direction of stronger occlusion.

All average ratings for the conditions with impression material were above 9.3, indicating that the impression material was an efficient means for completely occluding the ear canal. A correlation analysis of the occlusion ratings and the average VE between 200 and 400 Hz, which is the most critical frequency range for occlusion (Dillon, 2012), showed a highly significant negative correlation (Spearman's rho: -0.61, $p < 0.0001$).

DISCUSSION

The measured REOG indicates that all tested instant tips were, on average, acoustically transparent up to about 1 kHz except Double domes, which were transparent only up to about 600 Hz. Similar findings are described in Mueller *et al.* (2017). However, the data show substantial between-subject variability. A transparent tip may have a positive influence on the perceived sound quality for users with residual hearing at low frequencies, who will likely be able to fully utilize low-frequency acoustic cues. However, care must be taken for users who need amplification at low frequencies, because the interaction of the direct sound transmitted through the ear tip and the slightly delayed amplified sound from the HA can cause a comb filter effect. This effect is most pronounced when both sounds are similar in level (Dillon, 2012). If the REOG is known and considered in combination with the individual gain requirement, such comb filter effects can be reduced considerably.

All tested instant tips showed acoustic leakage (energy loss at low frequencies), even if no venting is intended. The average VEs can be grouped into three distinct acoustic identities for the five ear tips: open (Open), semi-open (Tulip, Round 1, Round 2), and semi-closed (Double). However, inter-subject variability was large, probably due to differences in coupling between tip and individual ear canal. These findings suggest that instant ear tips are not the best solution for patients who need significant low-frequency gain, because a lot of the signal generated by the HAs will 'escape' through the vent and not reach the eardrum. If a lot of gain is required at low frequencies, a custom earmold is still a better choice.

Especially the results for Double domes show a high inter-subject variability with VEs ranging from completely open for some subjects to completely closed for others. This suggests that compensating for the average vent loss might compromise sound quality for individual users, who would either experience loss of bass if their individual VE is larger than the average value or boominess if their VE is smaller. Hence, an estimation of the VE on an individual level is needed to apply a suitable amount of VE compensation. The large variability found in the study also highlights the importance of choosing the correct tip size for the individual ear canal to optimise the acoustic coupling between receiver and ear canal and thereby minimising the VE.

The test subjects' rating of occlusion correlates well with the measured VE, which is consistent with findings in Kiessling *et al.* (2005), showing the importance of choosing the right tip type for the individual client, based on their hearing loss profile. In the end, the hearing care professional will always need to find a compromise between comfort and acoustical demands. They have to select a tip that is open enough to avoid occlusion, while it is closed enough to allow for sufficient gain to match the fitting target.

CONCLUSIONS

On average, instant ear tips seal the ear canal less effectively than custom earmoulds, resulting both in more transparency for sounds from outside the ear canal and in a more pronounced VE. This is desirable for sloping hearing losses, because it reduces the occlusion effect. However, such ear tips might not be the best option for flatter losses that require gain also at low frequencies. Furthermore, the large inter-subject differences found in this study indicate the need for an individual in-situ estimate of the VE and REOG, since using inappropriate average values for VE compensation in the HA fitting can negatively impact the sound quality and lead to either a "boomy" or a "tinny" sound from the HA. Measuring the VE as part of the HA fitting procedure will give the best preconditions to maximise the sound quality for each end user individually, since this will allow the fitting software to provide the correct amount of gain for vent compensation and for avoiding comb-filter effects. Even though only Widex ear tips were used in the current study, we expect to find similar results for the instant tips from other manufacturers, since the coupling between each ear tip and the individual ear depends on the tip shape and size and the individual ear canal configuration. Ultimately, the results show that real-ear verification is crucial in clinical practice to verify that the prescribed gain has been matched.

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REFERENCES

Caporali, S. A., Schmidt, E., Eriksson, Å., Sköld, B., Popecki, B., Larsson, J., and Auriemmo, J. (**2013**). "Evaluating the physical fit of receiver-in-the-ear hearing aids in infants", J. Am. Acad. Audiol., **24**(3), 174–191.

Dillon, H. (**2012**). *Hearing aids*, Thieme, New York.

Hallenbeck, S. A., and Groth, J. (**2008**). "Thin-tube and receiver-in-canal devices: There is positive feedback on both!", Hear. J., **61**(1), 28–30.

Hearing Review (**2019**). "Hearing Aid Sales Increase by 3.8% in First Half of 2019", Retrieved September 12, 2019, from http://www.hearingreview.com/2019/07/hearing-aid-sales-increase-3-8-first-half-2019/

Jespersen, C. T., and Møller, K. N. (**2013**). "Reliability of real ear insertion gain in behind-the-ear hearing aids with different coupling systems to the ear canal", Int. J. Audiol., **52**(3), 169–176.

Keidser, G., Carter, L., Chalupper, J., and Dillon, H. (**2007**). "Effect of low-frequency gain and venting effects on the benefit derived from directionality and noise reduction in hearing aids", Int. J. Audiol., **46**(10), 554–568.

Kiessling, J., Brenner, B., Jespersen, C. T., Groth, J., and Jensen, O. D. (**2005**). "Occlusion effect of earmolds with different venting systems". J. Am. Acad. Audiol., **16**(4), 237–249.

Kuk, F., and Baekgaard, L. (**2008**). "Hearing Aid Selection and BTEs : Choosing Among Various " Open-ear " and " Receiver-in-canal " Options", Hear. Rev., **15**(3), 22–36.

Kuk, F., and Keenan, D. (**2006**). "How Do Vents Affect Hearing Aid Performance ?", Hear. Rev., **13**(2).

Kuk, F., and Nordahn, M. (**2006**). "Where an Accurate Fitting Begins : Assessment of In-Situ Acoustics (AISA)", Hear. Rev., **13**(7), 34–42.

Martin, R. L. (**2008**). "BBs: The hearing aids of the near future", Hear. J., **61**, 46–48.

Mueller, B. H. G., and Ricketts, T. A. (**2006**). "Open-canal fittings : Ten take-home tips", Hear. J., **59**(11), 24–39.

Mueller, H. G., Ricketts, T. A., and Bentler, R. (**2017**). *Speech mapping and probe microphone measurements*, Plural Publishing.

Pohlman, A. G., and Kranz, F. W. (**1926**). "The influence of partial and complete occlusion of the external auditory canals on air and bone transmitted sound", Ann. Otol., Rhinol. Laryngol., **35**(1), 113–121.

Smith, P., Mack, A., and Davis, A. (**2008**). "A Multicenter Trial of an Assess-and-Fit Hearing Aid Service Using Open Canal Fittings and Comply Ear Tips", Trends Amplif., **12**(2), 121–136.

Stenfelt, S., Wild, T., Hato, N., and Goode, R. L. (**2003**). "Factors contributing to bone conduction: The outer ear", J. Acoust. Soc. Am., **113**(2), 902–913.

Sullivan, R. F. (**2018**). "A Simple and Expedient Method to Facilitate Receiver-in-Canal (RIC) Non-custon Tip Insertion", Hear. Rev., **25**(3), 12–13.

Winkler, A., Latzel, M., and Holube, I. (**2016**). "Open Versus Closed Hearing-Aid Fittings: A Literature Review of Both Fitting Approaches", Trends Hear., **20**, 1–13.