BENEFITS OF DEEP-CANAL HEARING AID FITTINGS

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It has been suggested that completely-in-canal (CIC) hearing aids have advantages over behind-the-ear (BTE) hearing aids.

Some of these advantages include decreased occlusion (Mueller, 1994), increased patient satisfaction (Ebinger et al., 1994), decreased amplification of wind noise (Fortune & Preves, 1994), and improved localization ability (Best et al., 2010). If canal fitting of a hearing aid provides significant benefits over a BTE form factor, then it might be assumed that deep-canal hearing aid fitting could enhance those benefits. The premier option for deep-canal fitting is the Starkey SoundLens™, the industry's first invisible-in-the-canal (IIC) custom hearing aid. Traditionally, a CIC is fit one to two millimeters inside the aperture of the ear canal, whereas the IIC is fit to the second bend of the ear canal, positioning the faceplate well past the aperture. For additional background information on the IIC, please refer to Van Vliet and Galster (2010).

A research project was developed to investigate the benefits provided by the IIC as compared to CIC and BTE hearing aids; four experimental questions were asked:

1. Does the IIC hearing aid reduce some effects of own-voice occlusion when compared to the CIC and BTE fitting styles?
2. Does the microphone placement of the IIC hearing aid offer superior sound quality when compared to the microphone placement of CIC and BTE hearing aids?
3. Does localization ability improve with the IIC hearing aid when compared to CIC and BTE hearing aids?
4. Does the IIC offer improved maximum stable gain when compared to the CIC fitting style?

Five normal hearing research participants assisted in the systematic investigation of these questions. All IIC hearing aids used SoundLens technology. Both the CIC and BTE hearing aids were from the S Series™ iQ family of hearing aids; the BTE hearing aids used standard 13 size tubing coupled to a full-shell custom earmold. All fittings were done either without vents or with a pressure vent. This paper reviews the methodology used for evaluation and any clinically relevant outcomes.

Question 1: Own-voice Occlusion

When speaking, a person's own voice will be transmitted via bone conduction into his or her ear canal. For hearing aid wearers, the residual ear canal volume that resides beyond the medial end of the hearing aid will act as a resonant cavity for their own voices. This means that when wearing a hearing aid, a person's own voice will be louder than when he or she is not wearing the hearing aid. Mueller (1994) suggests that lengthening the canal portion of a hearing aid may reduce own-voice sound pressure levels (SPL) in a patient's occluded ear canal. For this reason it was expected that the IIC hearing aid would reduce the effects of own-voice occlusion when compared to the CIC and BTE hearing aids, both of which have shells that terminate in the cartilaginous portion of the ear canal. For the measurement of own-voice occlusion effect, participants were asked to vocalize a long /i/ at 65 dB SPL with and without IIC, CIC and BTE hearing aids. An Audioscan Verifit was used to record the real-ear unaided response (REUR) and real-ear occluded response (REOR) during vocalization.

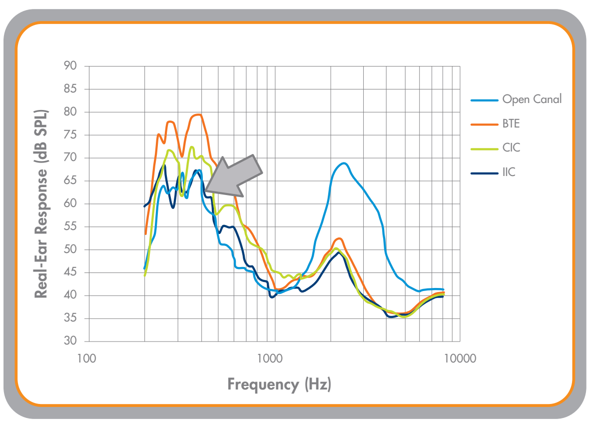

Figure 1. Average real-ear responses (dB SPL) are shown as a function of frequency (Hz) for open-canal, BTE, CIC and IIC hearing aid fittings. Each measurement was recorded during voicing of /i/ at 65 dB SPL. The arrow draws attention to the overlapping IIC and open-canal data.

Figure 1 shows the average results of the voiced occlusion measurements. As expected, the primary effect of voicing was observed between 200 and 500 Hz. Open-ear testing showed the lowest levels during vocalization; in contrast, BTE hearing aids resulted in the greatest voiced occlusion effect of the three hearing aid styles. The CIC data showed intermediate results and the IIC data indicated that on average the voiced occlusion effect is almost eliminated. This suggests that the IIC is a superior solution to the CIC and BTE for minimizing the negative effects of occlusion associated with a patient's own voice.

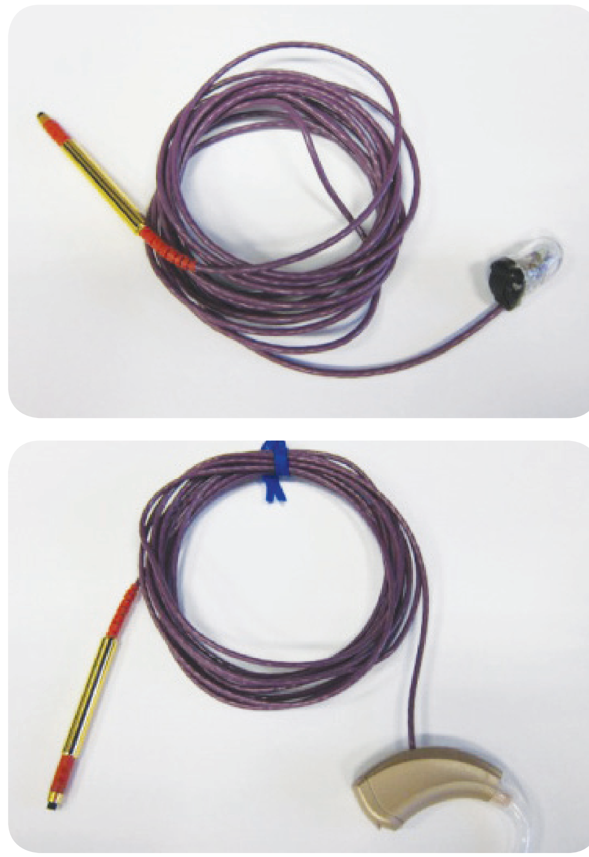

Figure 2. IIC and BTE hearing aids are shown. Each was specially prepared for recording; a cable has been attached to the hearing aid microphone for in situ audio recording.

Question 2: Sound Quality

The process of inserting and removing hearing aids makes it difficult to evaluate paired comparisons between device styles. For that reason, recordings were completed through specially prepared BTE, CIC and IIC style hearing aids. Examples of these research devices are shown in Figure 2. Each device was wired to allow for a direct recording from the hearing aid microphone while the patient wore each hearing aid. The recorded audio included samples of speech and music presented from directly in front of the listener.

Participants completed the paired comparisons of sound quality while wearing Etymotic ER-3a insert earphones. The recorded signals were presented at a level each participant judged to be comfortable. Each trial included the presentation of two stimuli (A and B); the participant made a judgment of preference for stimulus A or B using an on-screen graphical user interface (GUI). Signal presentation, randomization and response logging were managed by a custom Matlab program.

Figure 3 shows the outcomes of the sound quality judgments. Number of wins, or preferences, in a paired comparison task is plotted as a function of all possible comparisons for speech and music.

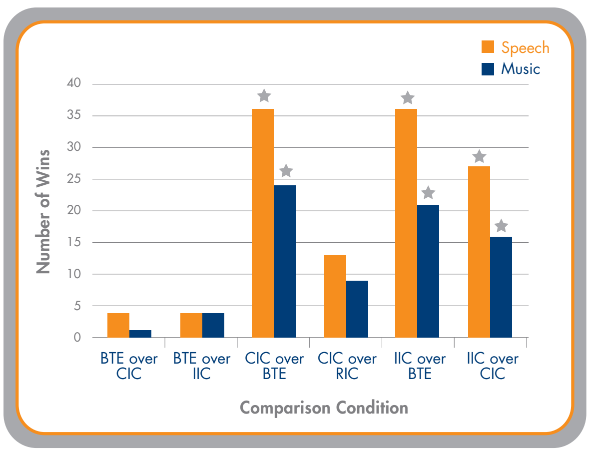

Figure 3. Number of wins for speech and music stimuli are plotted across all comparisons for judgments of preferred sound quality. Stars indicate a significant preference.

Similar trends were observed for speech and music stimuli. Participants showed significant preference for the IIC microphone location over both CIC and BTE microphone locations. The CIC microphone location was also preferred over the BTE microphone location. Anecdotal comments from the research participants suggested that they perceived the CIC and IIC hearing aids as providing a brighter or richer sound quality, when compared to the BTE hearing aids. Follow-up analysis of the test stimuli suggests that the microphone location of CIC and IIC hearing aids yields a high-frequency emphasis that may contribute to the preference for sound quality from the IIC.

Question 3: Localization

All localization testing used production quality BTE, CIC and IIC hearing aids programmed to meet DSL 5.0 through 6,000 Hz. During testing, participants were seated in an anechoic chamber with speakers located directly in front and directly behind their seated position. All sound field stimulus presentations (speech, music and broadband noise) were randomly presented from each speaker location at a calibrated level of 65dB SPL. Participants identified the sound source location via touchscreen interface on an Apple® iPad®.

A two-way repeated measures analysis of variance (ANOVA) was used to examine the main effects of stimulus type and fitting style. An alpha level of 0.05 was used for this and all other statistical analyses. Prior to statistical analysis, individual percent correct was converted to rationalized arcsine transform units (RAU) as a means of constraining error variance (Studebaker, 1985); all figures retain the percent correct format to ease interpretation.

ANOVA results showed a significant main effect of device style ($F1, 3=4.435$, $p<0.026$) with no other significant effects. No significant interaction effects were observed. The data were collapsed across stimulus type for further analysis. A one-way repeated measures ANOVA was completed, revealing a significant main effect of style ($p<0.001$). A pairwise multiple comparison (Tukey Test) was completed to further examine effects within the data set. The analysis suggests that localization ability with the CIC and IIC hearing aids is significantly different than localization ability with the BTE hearing aids, whereas localization ability between CIC and IIC hearing aids is not significantly different. These findings are in agreement with previous work that has shown improved localization ability when comparing CIC and BTE hearing aid fittings (Best et al., 2010).

Figure 4 shows the results of the final data analysis; the arrows illustrate the relationships between each hearing aid style. Specifically, CIC and IIC hearing aids significantly improved localization ability when compared to the BTE hearing aids. Thus, it is reasonable to expect that some patients will experience improved localization ability when going from BTE hearing aids to a canal style device.

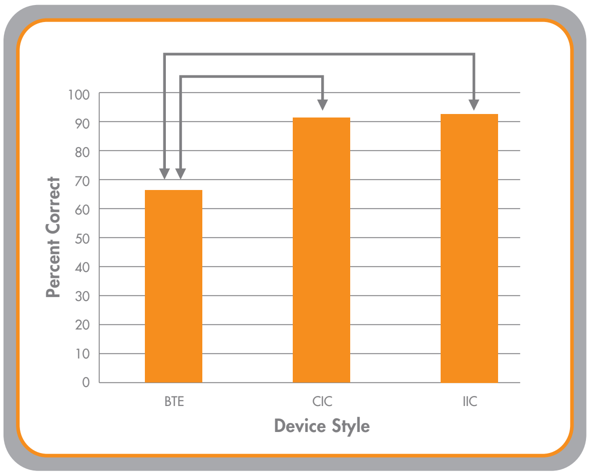

Figure 4. Percent correct is shown for front-to-back localization when wearing BTE, CIC or IIC hearing aids. Data shown are collapsed across stimulus types (speech, music, and noise). The arrows draw attention to the differences of interest within the data set.

Question 4: Maximum Stable Gain

The final research question asked whether or not the IIC fitting style would allow for improvement in available gain when compared to the CIC. During data collection, each participant placed a telephone next to his or her ear while each hearing aid's feedback canceller was initialized. The initialization process allows for estimation of a hearing aid's maximum stable gain. These modeled data were used for the comparison between styles. Due to telephone placement, it was felt that the BTE hearing aid style did not offer a valid direct comparison in these measures.

The results of comparative IIC and CIC maximum stable gain measures revealed significant improvements in the IICs maximum stable gain between 1,200 and 3,000 Hz. Specifically, the average IIC hearing aid fitting offered an additional 6dB of maximum stable gain when compared to the CIC hearing aid. This improvement may be the result of an improved fit in the ear with the IIC, or an increase in the efficiency of hearing aid performance resulting from decreased residual canal volume. These observations suggest that patients fit with IIC hearing aids may experience less feedback while talking on the phone than those fit with CIC hearing aids.

Conclusion

This study aimed to document select benefits of the IIC style of hearing aid. Four experimental questions were addressed: own-voice occlusion, sound quality, localization ability and maximum stable gain. Outcomes with the IIC hearing aids were compared to BTE and/or CIC hearing aids. The following observations were made:

When compared to BTE and CIC hearing aid fittings, deep canal hearing aid placement decreases own-voice occlusion effects.

Deep canal microphone placement improves sound quality when compared to BTE and CIC hearing aid fittings.

Front-to-back localization ability is improved with IIC and CIC hearing aids when compared to BTE hearing aids.

In a comparison between IIC and CIC hearing aids, the occurrence of feedback with IIC hearing aids was reduced when talking on the phone.

While existing work has focused on CIC hearing aids and comparative benefits to BTE hearing aids, modern hearing aid technology has made smaller, deeply fit hearing aids possible. These IIC hearing aids provide patients with an invisible hearing solution that leverages unique benefits of the wearer's pinna and ear canal to provide distinct benefits over other hearing aid form factors such as the traditional BTE and CIC hearing aid.

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