Procedural Considerations in the Real-Ear Measurement of Completely-in-the-Canal Instruments

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Abstract

Conventional procedures for measurement of the real-ear aided response (REAR) of hearing aids are performed by placing the probe tube 5 mm beyond the medial tip of the canal portion of the earmold or shell and within 5 mm of the tympanic membrane. Completely-in-the-canal (CIC) instruments insert more deeply into the ear canal, and thus may make adherence to conventional probe-microphone procedures impossible. The REAR was measured at several probe tube insertion depths, using two insertion methods: through a probe vent and alongside the CIC shell. Results indicated that conventional probe insertion depth is not necessary for CIC instruments and may place some clients at risk for discomfort due to contact of the probe tube with the tympanic membrane. Placement of the probe tube alongside the CIC shell rather than through a probe vent resulted in slit leak venting effects that were highly variable across subjects. A probe tube placement protocol for use with CIC instruments is suggested.

Key Words: Completely-in-the-canal aid, hearing aid, real-ear measurement

Abbreviations: BTE = behind the ear, CIC = completely in the canal, ITE = in the ear, REAR = real-ear aided response

C onventional procedures for the measurement of a real-ear aided response (REAR) require the placement of a probe tube alongside the canal portion of the hearing aid such that the tube extends at least 5 mm beyond the tip of the hearing aid and lies within 5 mm of the eardrum (Hawkins and Mueller, 1992; de Jonge, 1996). Also, the tube should not touch the eardrum (Tecca, 1990). This ensures that (1) the tube is measuring from within a diffuse soundfield area of the residual ear cavity; (2) the tube is measuring sound pressure levels similar to those received by the eardrum; and (3) subject discomfort due to contact of the probe tube with the eardrum is avoided.

With conventional hearing instruments (e.g., in the ear [ITE], behind the ear [BTE]), measurement of the REAR may be contaminated with several types of error if these procedures are not followed. If the probe tip is too close to the medial tip of the shell or mold, the high-frequency response is spuriously reduced (Larson et al., 1977). If the probe tip is too far from the eardrum, standing waves in the ear canal can introduce peaks and troughs into the REAR that do not exist at the eardrum (Hawkins and Mueller, 1986; Chan and Geisler, 1990). The magnitude of these measurement errors is largely governed by the volume of the ear canal beyond the medial tip of the hearing aid (Cox, 1979). In general, completely-in-the-canal (CIC) hearing instruments that terminate just beyond the second bend of the ear canal extend roughly...
7 mm to 8 mm deeper into the canal than a conventional instrument (Preves, 1994). Therefore, CICs are a distinct class of hearing instrument; a given protocol for conventional instruments may produce more or less measurement error when applied to CICs. Also, the deeper insertion of CICs may mean that the residual ear canal is not long enough to accommodate insertion of a probe tube to 5 mm beyond the CIC without contacting the eardrum. Clinicians may therefore be faced with a measurement protocol that is impossible to implement with CIC instruments without risking client discomfort.

The probe tube itself may also introduce measurement error. Often, placing the tube alongside the shell of the hearing aid causes or increases a slit leak, which may reduce low-frequency (e.g., 250 Hz) amplitude and increase mid-frequency (e.g., 750 Hz) amplitude because of a vent-associated Helmholtz resonance (de Jonge, 1996). The specific frequencies affected depend upon the length and diameter of the slit leak, the residual ear canal volume, middle ear status, and the characteristics of the hearing aid bore (de Jonge, 1996). Hawkins et al (1990) and Larson et al (1977) have suggested that hearing aids in actual use rarely have perfect seals, and that slit leaks in real-ear measurement may, in fact, accurately represent the wearer's true real-ear response. However, this assumes that the size of the slit leak is small, and that it is typical of slit leaks that occur during normal use. This assumption may hold with conventional hearing aids, as their termination in the softer cartilaginous portion of the ear canal may accommodate some of the diameter of the probe tube. In contrast, CIC hearing aids may terminate at or in the bony portion of the ear canal. This may increase the chance that a slit leak is present during real-ear measurement, and may exacerbate the size of the slit leak. Some manufacturers produce CIC instruments with a probe tube inserted through the shell of the instrument, which may lessen the impact of slit leaks since the probe tube does not lie outside the diameter of the CIC shell.

In summary, procedures for probe tube placement were developed with conventional hearing aids and may not be relevant to CIC instruments. The purpose of Experiment 1 was to determine the effect of probe tube insertion depth on the measurement of the REAR of CIC instruments. Experiment 2 was conducted to determine the effect of probe tube insertion method on REAR measurement and to quantify slit leaks associated with CICs.

### METHOD

#### Subjects

In total, 21 adult subjects (age range 24–37 years; 17 female, 4 male) participated in this investigation. A subset of the subjects (n = 10) participated in Experiment 1. All subjects participated in Experiment 2. All subjects had normal hearing and ear canals large enough to accommodate a CIC instrument.

#### Instrumentation

A “dummy” CIC instrument was manufactured for each subject. Each dummy CIC contained a standard hearing aid microphone and receiver in a typical CIC shell, which had been tapered at the medial end. The microphone was disabled in this study and was present in order to accurately represent the size of a true CIC instrument, and for the purposes of a separate study on microphone location effects (Cornelisse and Seewald, 1997). Each instrument contained a vent large enough to accommodate a probe tube (ER7-14C). All instruments were recessed at least 1 mm in the external ear canal, and the mean length of the instruments was 19.4 mm.

White noise from a Bruel and Kjaer (B&K) 3106 signal generator was fed electrically to the receiver in the dummy CIC via a custom cable and interface box. The cable used was similar to those used for connecting programmable hearing instruments to computer interfaces. The REAR of the white noise signal was measured in dB SPL for 1/24-octave bands. The real-ear measurement equipment was a probe tube microphone and preamplifier (ER-7) connected to a B&K 2035 signal analyzer. The calibration of this measurement apparatus was verified at each test session.

#### Procedures

**Experiment 1**

Measures of the REAR (dB SPL in the ear canal) were made with the probe tube inserted through the probe vent. Prior to measurement, the tube was inserted until the probe tube tip was flush with the medial end of the hearing aid (i.e., 0-mm insertion depth). The CIC was placed in the subject's ear and a REAR was measured. This measurement was repeated with the probe tube inserted to 2, 4, and 6 mm beyond the tip of the CIC. If subjects reported sudden discomfort as
insertion depth was increased, a measurement was not taken. In total, 4 of 10 subjects (40%) reported discomfort during incrementation of probe depth from 4 mm to 6 mm.

Experiment 2

For all subjects, a REAR measure was made at 4-mm insertion depth with the tube inserted through the probe vent. A second REAR measure was made with the probe tube inserted between the CIC and the ear canal, using conventional insertion procedures. The probe tube was placed to a standard insertion depth from the intertragal notch (females = 28 mm, males = 31 mm), and the dummy CIC was seated in the canal alongside the tube. This standard insertion depth is expected to place the probe tube to within 5 mm of the tympanic membrane. A REAR was measured using procedures described above. The probe vent was plugged at the medial end with putty during this measurement.

RESULTS

Experiment 1

A comparison of the average REARs for the four insertion depths is shown in Figure 1. Data were pooled for only those ears in which the REAR was measured at all four insertion depths. This elimination of subjects who could not tolerate the 6-mm insertion depth ensures a completely within-subjects comparison in Figure 1, thus reducing bias for larger ear size that would have been present in partial data. Measures taken at the four insertion depths resulted in essentially equivalent levels from 100 Hz to 6220 Hz (average difference = 0.5 dB, largest difference = 2.5 dB). It can be seen in Figure 1 that some high-frequency resonances were present, with the effects of probe tube insertion depth evident in the region of 6220 to 10,000 Hz. At the second peak of the measured response (8300 Hz), each increase of 2 mm in insertion depth resulted in an average increase of 2.8 dB.

Experiment 2

Figure 2 shows the average of the REAR measures taken using conventional probe placement versus measures taken through the probe vent at 4-mm insertion depth. On average, lower sound pressure levels were measured for conventional probe tube placement from 100 to 392 Hz, relative to measurement through the probe vent (average difference = 2.9 dB, greatest difference = 3.7 dB). Above 392 Hz, the conventional measurement agreed with the probe vent measurement within 1.1 dB. This pattern is consistent with a slit leak produced by the placement of the probe tube alongside the CIC shell. Figure 3 shows the individual and average effects of slit leak venting. These effects were calculated as the difference between REARs measured using conventional probe tube placement, and placement at 4-mm insertion depth through a probe tube vent. Individual slit leak effects had an overall range of approximately 15 dB across subjects. On average, slit leak venting affected the REAR by less than 4 dB below 400 Hz, with
Figure 3 (a) Individual slit leaks, in dB as a function of frequency, attributable to the presence of the probe tube alongside the CIC shell. (b) The average slit leak effect, in dB as a function of frequency, attributable to the presence of the probe tube alongside the CIC shell (n = 21).

DISCUSSION

The finding that probe tube placement does not seriously influence the REAR is unlike results of previous studies completed on conventional hearing aid styles. Dirks and Kincaid (1987) reported substantial differences between measures of real-ear sound pressure level taken with a probe tube located at the earmold tip versus at the eardrum (9 dB at 6 kHz, 5 dB at 4 kHz). Similarly, Hawkins and Mueller (1986) and Larson et al (1977) measured large reductions in sound pressure level when probe tube insertion depth was reduced to 0 mm beyond a BTE earmold tip from either 10 mm or 5 mm (approximately 4 dB at 4 kHz, 6 dB at 6 kHz). In contrast, the present study found no effects of probe tube insertion depth larger than 2.5 dB from 0 mm to 6 mm beyond the CIC tip until the measurement frequency exceeded about 6000 Hz. Above 6000 Hz, probe tube insertion depth effects were measured, with peak effects seen at about 8000 Hz. At present, these effects are not clinically significant because hearing aid frequency responses typically roll off at frequencies above 6000 Hz (Dirks and Kincaid, 1987), and because the prediction of true eardrum SPL above this frequency is dependent upon both probe tube insertion depth and vertical placement relative to the eardrum (Stinson, 1985; Chan and Geisler, 1990).

The present study also found that REAR measures could not be collected on 4 of 10 subjects at merely 6 mm beyond the CIC tip without subject discomfort, likely due to contact with the eardrum. Tecca (1990) recommends selecting an insertion depth that will accurately estimate eardrum sound pressure level without risking contact with the eardrum. The results of this study indicate that a target insertion depth of more than 4 mm beyond the tip of CIC instruments brings too great a risk of client discomfort, and is not warranted based on the minimal effects of probe tube insertion depth shown in Figure 1.

Estimates of slit leak effects in CIC instruments are in agreement with Cox's (1979) work on conventional instruments. In an unvented instrument, Cox found that slit leakage caused a reduction of only about 1 dB at 200 Hz accompanied by negligible vent-associated resonance. Figure 3b shows a similar pattern, in that average slit leak venting effects in this study were less than 4 dB in magnitude, with little vent-associated resonances. However, the average slit leak effect is not a good predictor of slit leak venting found in individual subject data, shown in Figure 3a. The higher individual variability in the low frequencies is consistent with the effects of slit leaks reported in previous studies (Hawkins et al, 1991; Sinclair et al, 1996). However, the effects of slit leaks in some subjects affected frequencies above 500 Hz, which is inconsistent with expected slit leak effects in conventional instruments (de Jonge, 1996).

Slit leak venting effects are produced by the acoustic mass of the slit leak and the acoustic compliance of the residual ear canal volume (Cox, 1979). In CIC instruments, the smaller residual volume and small size of the slit leak

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1 The high-frequency effects in Figure 3 are attributable to slight differences in probe tube placement between the conventional and probe vent placement.
will create a Helmholtz resonance that may differ from those in conventional instruments. The highly variable and rather large slit leak effects for some individuals may indicate that it is preferable to make real-ear measures of CICs through a probe vent rather than with conventional probe tube placement alongside the CIC shell whenever possible. Alternatively, the CIC may be measured in a coupler and a REAR may be predicted using an appropriate transform (Seewald et al, 1997).

**SUMMARY**

The primary findings of this study are (1) the insertion depth of a probe tube beyond the tip of a CIC instrument has no effect on the measurement of the REAR for frequencies below 6220 Hz, and (2) placement of the probe tube alongside the CIC shell can cause highly variable slit leak effects that may be as large as 10 dB at 250 Hz in some individuals.

The clinical implications of these findings are that measurement of the REAR for CIC instruments requires different clinical protocols than those used for conventional instruments. Probe tube placement protocols should fulfill three goals:

1. The tube is measuring from within a diffuse sound field area of the residual ear cavity;
2. The tube is measuring sound pressure levels similar to those received by the eardrum; and
3. Subject discomfort due to contact of the probe tube with the eardrum is avoided.

The results of the present study indicate that a conventional probe placement to 5 mm beyond the CIC tip, with the tube external to the CIC shell, will meet neither the second goal due to large and unpredictable slit leak effects, nor the third goal due to discomfort in some ears. A more consistently accurate method is achieved with the probe tube inserted through a probe vent drilled into the CIC instrument, which reduces slit leak error. As well, a probe tube insertion depth of 4 mm beyond the CIC medial tip is sufficient to accurately represent sound pressure levels at the eardrum.

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**REFERENCES**


