1aNS1. Attenuation as a function of the canal length of custom-molded earplugs

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The fit of a custom-molded earplug (CMEP) and the amount of attenuation it provides can be affected by variables related to the original earmold impression and the subsequent manufacturing process. One variable thought to affect the amount of attenuation is the length of the canal portion of the CMEP. In this pilot study, we systematically examined the relationship between CMEP canal length and attenuation in four human subjects. Two men and two women were fitted with CMEPs extending past the second bend of the ear canal. The attenuation provided by the CMEPs was measured over four visits to the laboratory. Prior to each visit, the canal portion of the subject's test CMEP was shortened by 2mm. As expected, attenuation decreased as canal length decreased for all subjects. However, the rate and pattern of decrease varied markedly. Anecdotal reports of comfort as a function of canal length also varied markedly. Results suggest that the critical region/s in the ear canal for maintaining a good acoustic seal may vary from person to person. Implications for future study will be discussed.

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INTRODUCTION

The fit of a custom-molded earplug (CMEP) and the amount of attenuation it provides can be affected by variables related to the original earmold impression and the subsequent manufacturing process. One variable known to affect the amount of attenuation is the length of the canal segment, with longer segments providing greater attenuation (e.g., Du et al., 2008; Norris et al., 2011). A longer canal segment increases the likelihood of an airtight seal in the ear canal (Macrae, 1990) and reduces the ear-canal-wall area available to vibrate.

For maximal attenuation, the canal segment should extend beyond the second bend of the ear canal. Medial to the second bend, however, the ear canal can be very sensitive to pressure (Pirzanski, 1997). For this reason, some individuals find deep-insertion CMEPs to be uncomfortable at first fitting. While some wearers can acclimate to an initially uncomfortable fit, those who cannot tolerate a deep-insertion CMEP may require it to be modified or shortened, possibly sacrificing attenuation. Thus, the function relating attenuation to canal segment length for individuals is important to map.

In this pilot study, we systematically examined the relationship between CMEP canal segment length and attenuation in four human subjects, using a within-subjects design. Anecdotal reports of comfort were also obtained.

METHODS

Participants and custom earplugs

Two men and two women participated in the study (mean age = 24.8 years; SD = 0.5). Participants had normal hearing, clear ear canals, and no evidence of outer- or middle-ear pathology. The ear with better air- and bone-conduction thresholds was the test ear.

Binaural closed-jaw impressions of the participants’ ear canals were taken. Each impression was examined as to its quality and the visibility of anatomical landmarks. Custom-molded earplugs (CMEPs) of solid silicone were manufactured by Westone Laboratories Inc. from these impressions. The canal segment of each CMEP extended well past the second bend of the ear canal.

Earplug modification

Over the course of the study, the canal segment of each CMEP was shortened in 2-mm increments. This was done by abrading the tip of the canal segment to the appropriate length and then tapering it slightly using a dental drill (Buffalo V35 Handpiece System) with a blue grinding stone. Several markings were made on the unmodified CMEPs to serve as visual references. Four axis lines were drawn: one each in the superior and inferior horizontal planes and one each in the anterior and posterior vertical planes as the CMEP would appear in the ear canal. Each line followed the contours of the canal segment. The aperture ring (i.e., the junction of the concha portion and the canal segment) was drawn on the CMEP. Finally, six rings were drawn around the canal segment to mark the lengths to which it was to be shortened. The rings intersected the superior horizontal axis line at right angles, 2 mm from one another. The rings were drawn so that the cut plane of the canal segment would be orthogonal to the direction of the canal segment. Canal segment length was measured by placing one end of a length of crochet thread at the aperture ring, following the contours of the superior horizontal axis line, marking the thread at the tip, and then measuring the thread length. In each case, the mean of three measurements was taken.

Earplug attenuation measurement

Earplug attenuation was measured in a single-walled, sound-treated booth (IAC Model 403) using a real-ear-attenuation-at-threshold (REAT) procedure (ANSI, 2008). Hearing thresholds in the test ear were measured for pulsed 1/3-octave-band noises with center frequencies of 125, 250, 500, 1000, 2000, 3150, 4000, and 6300 Hz. A full REAT test consisted of an “open” run (i.e., threshold measurements with the test ear open) and an “occluded” run (i.e., threshold measurements with the test ear occluded by the CMEP). The attenuation at a given test
frequency was the difference between the occluded and open thresholds at that frequency. During all testing, the non-test ear was occluded by a deeply inserted foam earplug (3M™ E-A-R™ Classic™ PLUS) covered by an earmuff (Peltor Optime 101 H7A). The Fitcheck2 Insert Hearing Protector Attenuation Measurement System (Michael and Associates, Inc.) controlled stimulus generation and threshold acquisition. Stimuli were routed to three Electro-Voice SX100+ loudspeakers in the sound-treated booth. Speaker output levels were stable over the course of the study.

**Procedures**

Each subject made seven visits to the laboratory. At each visit, the subject completed four REAT tests. At the first visit, the subject was tested with the unmodified CMEP. Before each of the next six visits, the canal segment was shortened by 2 mm. Thus, seven canal segment lengths were tested in total. At the end of each visit, the subject was asked whether the CMEP was comfortable to wear.

**RESULTS AND DISCUSSION**

Overall trends are described, although minor exceptions occurred. First, attenuation decreased as canal segment length decreased. The decrease was more pronounced for frequencies at and below 1000 Hz (median decrease = 25 dB) than for frequencies at and above 2000 Hz (median decrease = 10 dB). Second, for all but one subject, the removal of certain 2-mm sections of the canal segment resulted in particularly steep drops in attenuation at more than one frequency. These regions were not consistently located from one individual to the next. They included the region falling between the first and second bend and regions located in the vicinity of the second bend. The two male subjects found their CMEPs to be comfortable at every visit. Both of the female subjects found their CMEPs uncomfortable until the portion that lay beyond the second bend was removed. Some attenuation was sacrificed in order to make their CMEPs comfortable.

The results of this pilot study are preliminary. Recommendations for future work include testing a larger range of canal segment lengths and examining the effect of snugness of fit in conjunction with canal segment length. In addition, subjects should be allowed to acclimate to their CMEPs. Evaluation of comfort following acclimation would provide a more realistic measure of the acceptability of the CMEPs.

**CONCLUSIONS**

For all four CMEPs tested in this study, attenuation decreased as canal segment length decreased. The decrease was generally greater for frequencies at and below 1000 Hz compared with frequencies at and above 2000 Hz. Some regions of the canal segments were particularly important in maintaining attenuation. The location of these regions varied from individual to individual and included the area between the first and second bends and the area in the vicinity of the second bend. The canal segment of a CMEP should extend beyond the second bend in order to ensure maximum attenuation. At first fitting, some wearers may find canal segments of this length to be uncomfortable, as did two of the participants in this study. A period of acclimation may improve acceptability of the CMEP so that attenuation does not have to be sacrificed.

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**REFERENCES**
