The Effectiveness of Acoustically-Tuned Earmolds

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Despite the latest technology, behind-the-ear hearing aids are limited in their ability to provide substantial gain in the high frequencies. Consequently, earmold modifications have been developed to compensate for this shortcoming. Two such modifications include the Libby horn tubing and the Continuous Flow Adapter (CFA) earmold. Results from three individuals indicated significant increases in gain for both modified earmolds compared to an earmold with #13 tubing, although the gain from the CFA earmold was considerably less than expected. Word recognition scores and sound quality judgements were equivocable.

For the majority of individuals with hearing impairments, hearing deficits are characterized by a greater loss in the high frequencies than the low frequencies.

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This results in decreased ability to perceive high frequency phonemes, most notably sibilants and fricatives. Approximately 95% of speech intelligibility is attributed to consonant perception (Gerber, 1974) and word recognition scores have been shown to improve with the use of high frequency emphasis amplification, especially in the presence of background noise (Schwartz, Surr, Montgomery, Prosek, & Walden, 1979).

The need to provide emphasis in the high frequencies is unequivocable. Yet, despite technological advances in the hearing aid industry, it remains difficult to obtain much amplification beyond 3000 Hz (Killion, 1984). Dispensers have to pursue other means in hope of obtaining a few more decibels of high frequency gain. Many dispensers take advantage of the concha effect and microphone placement by using in-the-ear (ITE), in-the-canal (ITC), or completely-in-the-canal (CIC) hearing aids. Behind-the-ear (BTE) hearing aids, however, can not take advantage of microphone placement. If a BTE is the hearing aid of choice, high frequency emphasis must be enhanced through earhook and earmold modifications.

Techniques to provide increased amplification above 2000 Hz through earmold modifications have been commercially available for the last 25 years. Development of acoustically-tuned earmolds began with the introduction of stepped-diameter tubing (Lybarger, 1985). Killion continued work in the area of acoustically-tuned earmolds and developed a system of earmold tubing that consisted of (a) stepped-diameter tubing, and (b) the placement of dampers at points of nodes. These earmolds (e.g., 6R12 or 8CR; Killion, 1976, 1979, 1981; Knowles & Killion, 1978) provided smooth frequency responses and an enhanced high frequency response. Although these earmold configurations achieved the desired effect, there were problems with the design; the tubing was considered cosmetically unappealing, the tubing was difficult to replace, the dampers were susceptible to moisture, and the desired effect was altered by the change in overall tubing length (Lybarger, 1985). Using the same principles as the Killion tubing, the Libby horn was developed (Libby, 1981). The Libby horn provided greater stability, improved cosmetic appeal, and was not as susceptible to the same moisture problems (Lybarger, 1985).

Although the Libby horn offered some advantages over the Killion tubing system, it was not without limitations, mainly the possibility of altering the frequency response by improper insertion or crimping of the tube. Consequently, a number of new developments in earmold acoustics have been introduced including the Continuous Flow Adapter (CFA) modification. The CFA is a combination of an elbow placed in the earmold (to attach the tubing from the earhook to the earmold) and the boring of the canal of the earmold, utilizing Helmholtz resonance theories. The CFA earmolds have been designed to reportedly provide additional gain between 2000 and 5000 Hz. The degree of additional gain is dependent upon the specific CFA earmold, yet range from a few decibels to as much as 20 dB, according to advertisements from various earmold laboratories. The CFA #4, reportedly, has been designed to provide 10 to 20 dB of gain over an earmold with standard #13 tubing. The authors' clinical experiences with CFA earmolds have fallen short of the advertised values. It was the purpose of this study, therefore, to more systematically investigate the degree of high frequency emphasis obtained from acoustically-tuned earmolds. Because fitting of hearing aids is highly individualized, a case study format was chosen as the experimental design of the study. Three cases will be presented: one adult with normal hearing who served as the pilot subject, followed by two individuals with hearing losses who were each excellent candidates for earmold modifications.

CASE ONE

Subject 1

The first subject was a 23-year-old male (S1) with normal hearing. He was a student in a graduate speech-language pathology program at the time of testing. For testing he was fitted with a Phonak Pico SCD BTE hearing aid, a mild gain hearing aid, to the right ear. Although the results of each earmold were compared to one another rather than to a prescriptive curve, a mild high frequency hearing loss was entered into the program for real ear testing.

Earmolds

An impression was made for the right ear and sent to an earmold laboratory (earmolds were provided at no cost for all 3 subjects). All earmolds were made from the same impression.

Four lucite skeleton earmolds with select-a-vents were ordered: CFA #2, #3, #4, and an earmold with standard #13 tubing. The reported expected additional gain for 2000 to 5000 Hz was 5-8 dB for CFA #2, 8-12 dB for CFA #3, and 10-20 dB for CFA #4.

Procedures

The earmolds were fitted to the subject's right ear along with the hearing aid. With the subject using the earmold with the standard #13 tubing, the volume control was adjusted to ½ on and was reported to be comfortable for the user and not too loud. This setting yielded a maximum output of 94 dB SPL when coupled to the earmold with standard #13 tubing. The volume control was taped in place for the remainder of the testing. The test earmolds were coupled with the hearing aid and tested in a random order.

Real ear insertion measurements (REIRs), using a Madsen IGO, were obtained by presenting a 60 dB SPL warble pure tone sweep stimulus. The probe tube microphone was marked to extend 5 mm past the longest earmold canal. The probe was inserted and taped in place. A hard copy of the REIRs was made for all the measurements and the curves were cursored to obtain the data points for each tracing.

Results

Real ear aided responses for the three CFA earmolds for S1 are shown referenced to the earmold with #13 tubing in Figure 1. Note that the values above the line represent greater gain than the earmold with #13 tubing and values below the line represent gain less than the #13 tubing.

The three CFA earmolds fell short of the expected values. For CFA #2, the actual increase was 2 to 5 dB less than the advertised figures. For CFA #3, the actual increase was 3 to 7 dB less than reported and for CFA #4, the actual increase was as much as 15 dB less than the maximum reported values. However, all three CFA earmolds did provide greater amplification when compared to

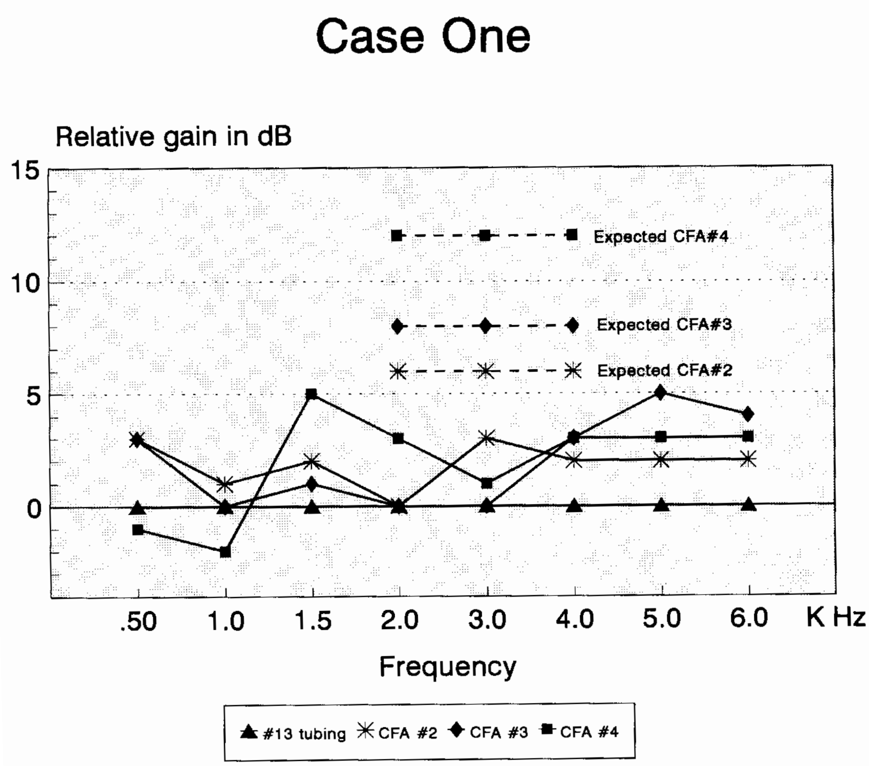

Figure 1. The real ear responses obtained for S1. The three CFA earmolds' values are presented relative to the earmold with #13 tubing so that values above the 0 line represent gain greater than obtained with the #13 tubing earmold and the values below the line represent less gain than with the earmold with #13 tubing.

the earmold with standard #13 tubing.

The results of this initial project led the authors to examine the effect of CFA earmolds in 2 subjects who were hearing aid users.

CASE TWO

Subject 2

This subject (S2) was a 61-year-old female with normal hearing sensitivity through 500 Hz gradually sloping to a mild-to-moderate sensori-neural hearing loss through 8000 Hz for the right ear (test ear). The left ear (nontest ear) had no measurable responses from 250-8000 Hz. Prior to testing, the subject had been wearing a Telex 340 BiCros hearing aid system coupled to a lucite skeleton earmold with #13 tubing and select-a-vents for approximately 1 year. Word recognition was assessed using W-22 word lists. For her right ear, unaided word recognition score under headphones was 92% at 50 dB HL. Aided and unaided word recognition testing was conducted in sound field (45 dB HL) with the signal directed to her poorer ear or 180° azimuth to her better ear and yielded a score of 48% unaided and 72% aided.

Earmolds

Three soft, skeleton earmolds with select-a-vents were ordered: a CFA #4 earmold, an earmold with 4 mm Libby horn tubing, and an earmold with standard #13 tubing. The same procedures were followed as in Case 1.

Results

Real ear insertion responses for S2 are shown in Figure 2. The top graph (A) illustrates the REIR for the three earmolds, the bottom graph (B) shows the relative gain of the CFA and Libby horn earmolds compared to the earmold with #13 tubing. As in Figure 1, the values above the line represent greater gain than the earmold with #13 tubing and values below the *0* line represent gain which is less than the earmold with #13 tubing.

All three earmolds provided a relatively smooth frequency response. The Libby horn clearly provided the most gain across all frequencies. The CFA #4 earmold provided more gain than the earmold with #13 tubing but less than the earmold with the Libby horn. The amount of increased gain compared to the earmold with #13 tubing can be more clearly seen in Figure 2-B. The Libby horn provided as much as 11 dB more gain than the earmold with #13 tubing and this pattern was consistent for the frequencies 2500 to 4000 Hz. The CFA #4 earmold, on the other hand, provided approximately 6 dB of increased gain over the earmold with #13 tubing for the frequencies between 3000 Hz and 4000 Hz, falling to comparable levels of the other two earmolds at 5000 and 6000 Hz.

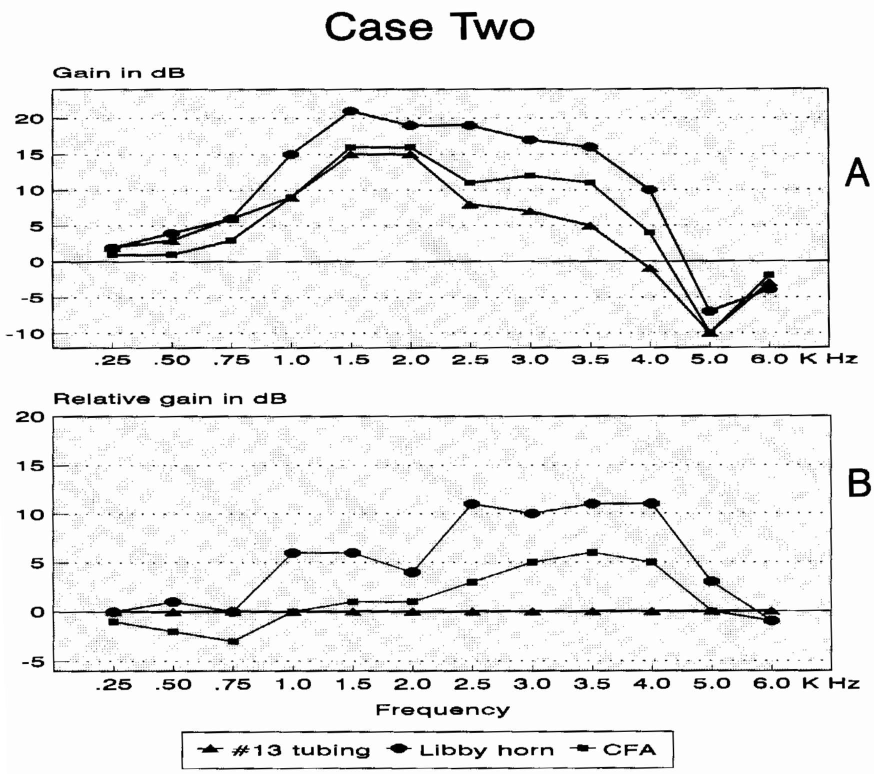

Figure 2. The real ear responses obtained for S2. The top panel (A) represents the real ear insertion response (in dB gain) obtained from the earmold with standard #13 tubing (the triangle), the earmold with Libby horn tubing (closed circle), and the CFA earmold (the closed square). The bottom panel (B) represents the relative gain of the Libby horn earmold and the CFA earmold compared to the earmold with #13 tubing. Values (in relative dB) above the 0 line represent gain greater than the #13 tubing earmold with values below the 0 line indicating less gain than the earmold with #13 tubing.

Word Recognition and Sound Quality Testing

In addition to the real ear measurements, the two subjects (S2 and S3) who were hearing impaired were administered the California Consonant Test (CCT; Owens & Schubert, 1977). Subjects were seated at 0° azimuth 1 m from the loudspeaker and the lists were presented in a quiet sound field at 55 dB HL. Twenty-five words were presented for the assessment of each earmold. The earmolds were tested in random order. At the completion of each list, both subjects were asked to give a subjective opinion of the sound quality and ease of listening for each earmold. The subjects were instructed to indicate for which earmold they found the sound to be the most pleasant and for which earmold they had the least amount of listening difficulty.

The percentage correct scores for the CCT are presented in Table 1. S2 obtained a 76% using the CFA #4 earmold, a 68% with the earmold with Libby horn tubing, and a 58% using the earmold with #13 tubing. According to the Thornton and Raffin (1978) table of binomial distribution for speech recognition scores, these results are not statistically different. Interpretation of these results, however, must be made with caution. To the authors' knowledge, the reliability and error scores when using 25 word lists of the CCT has not been investigated. Owens and Schubert (1977) demonstrated equivalency for 50-item lists, suggesting that a difference could be considered significant if there was at least a 14 percentage point difference but the use of 25 words was not investigated. Therefore, caution must be used when interpreting the obtained percentages on the 25-item CCT lists for comparison purposes.

Perhaps more important than the scores was the reported preference for the sound quality and ease of listening. S2 reported a definite preference for the Libby horn earmold over the other two tubing types.

Table 1
Percentage Scores Obtained from the California Consonant Test

	Subjects	
Earmolds	**S2**	**S3**
#13 tubing	58%	52%[a]
Libby horn	68%[a]	32%
CFA #4	76%	24%

[a]preferred earmold for sound quality

CASE THREE

Subject 3

The third subject (S3) was a 13-year-old male who has had a bilateral severe-to-profound sensori-neural hearing impairment since birth. He was identified and aided at approximately 18 months of age. At that time he was enrolled in an auditory-verbal (A-V) program and has been receiving A-V therapy on a regular basis since. At the time of this project he was wearing binaural Oticon E 38 P hearing aids coupled to soft, shell earmolds with standard #13 tubing. His unaided speech detection scores, under headphones, were 85 dB HL for each ear. Aided speech recognition thresholds were not assessed during this study and were not available to the investigators. Aided warble tone and narrow band thresholds were assessed, however, at 40 dB HL for frequencies 250 through 2000 Hz falling to 50 dB HL for 4000 Hz.

Earmolds

Three shell, unvented, soft earmolds were ordered: a CFA #4 earmold, an earmold with 4 mm Libby horn tubing, and an earmold with standard #13 tubing.

Procedures

The same procedures followed for S1 and S2 were used for S3.

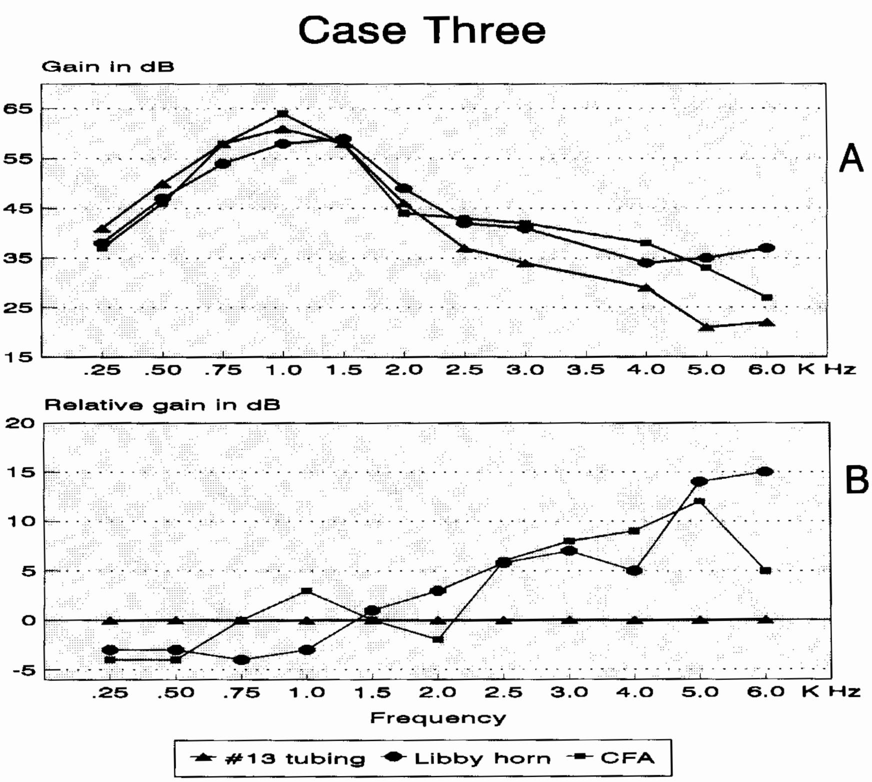

Figure 3. The real ear response for S3. The top panel (A) represents the real ear insertion response (in dB gain) obtained from the three earmolds: the #13 tubing earmold (the triangle), the Libby horn earmold (closed circle), and the CFA earmold (the closed square). For the bottom panel (B), the values of the earmold with #13 tubing have been equated to 0. Values above the 0 line represent more gain provided than the #13 tubing earmold, with values below the 0 line indicating less gain than the earmold with #13 tubing.

Results

For S3, similar results occurred as for S2 and are shown in Figure 3. All three earmolds provided smooth frequency responses (Figure 3-A) with the Libby horn providing less gain for the lower frequencies (1000 Hz and below) and approximately 5 to 15 dB more gain for the higher frequencies (5000-6000 Hz) when compared to the earmold with #13 tubing (Figure 3-B). The CFA yielded less gain for the lowest frequencies (250 and 500 Hz), essentially comparable gain to the earmold with #13 tubing for the mid frequencies (750 to 2000 Hz), and a steady upward increase of gain from 6 to 12 dB for the higher frequencies. When comparing the CFA earmold and the Libby horn earmold, the responses were similar with a few notable exceptions. For the lower mid-frequencies (750-1000 Hz), the Libby horn earmold provided less gain than the CFA earmold and approximately 10 dB more gain in the 5000 to 6000 Hz range.

Word Recognition Testing

S3 obtained a 52% correct score with the earmold with #13 tubing, a 32% score with the earmold with the Libby horn, and 24% with the earmold with the CFA #4. Based on the Thornton and Raffin (1978) tables, the scores from the earmold with standard #13 tubing and the CFA earmold were statistically different from each other. The scores obtained from the Libby horn earmold were not different from the earmold with #13 tubing. (Again, caution must be taken when interpreting these findings.) He also indicated that he preferred the earmold with #13 tubing over the two modified earmolds for sound quality and ease of listening.

DISCUSSION

To compensate for the lack of amplification in the high frequencies available from BTE hearing aids, acoustic modifications need to be made to the earmolds. Two such modifications include Libby horn tubing and Continuous Flow Adapter (CFA) earmolds.

Industry advertisements report that the CFA earmolds will increase the gain in the high frequency region by as much as 20 dB over the earmold with #13 tubing. Although the results from these three case studies support an increase in high frequency gain compared to the #13 tubing earmold, the amount of gain fell substantially short of the advertised expected results. These findings support the authors' initial clinical findings.

Although the CFA earmolds fell short of the expected results, they, nevertheless, provided additional gain over the standard #13 tubing with a relatively smooth frequency response. This in and of itself should be justification for use of CFA earmolds. Any additional increase in gain for the high frequencies is desirable.

When compared to the Libby horn tubing, the CFA earmolds provided slightly less gain but the use of a CFA versus a Libby horn should be determined on an individual basis. The use of CFA earmolds may, in fact, play an important role when fitting children, individuals with profound hearing losses making use of high gain hearing aids, or situations when the use of a Libby horn may be contraindicated because of size restrictions and potential feedback.

Beyond the actual frequency response of the acoustically-modified earmolds, their effect on word recognition was examined. Using a word recognition test designed to assess high frequency phonemes, the CCT was administered to the two individuals with hearing impairment (Owens & Schubert, 1977). S2 obtained the best score on the CCT with the CFA earmold, the earmold providing the second highest amount of high frequency emphasis. On the other hand, she preferred the sound quality and reported the greatest ease of listening with the Libby horn earmold. The difference between her performance with the CFA earmold and the Libby horn earmold, however, was not statistically significant and probably not clinically significant. What may be significant was her preference for one earmold over the other.

S3, on the other hand, preferred the sound quality of and performed best on the CCT with the earmold with #13 tubing. S3 has been wearing earmolds with #13 tubing for a number of years and has "learned to listen" through that system. His scores and his preference may be a reflection of that fact. Considering the significant degree of his hearing impairment, it is expected that he may be unable to immediately make use of the additional high frequency information provided to him with the modified earmolds. However, given an opportunity to adjust to the modified earmolds, it is possible that his preference would change and his CCT scores would improve, reflecting the adaptation and utilization of the additional high frequency information provided by the acoustically-tuned earmolds.

It is possible that both subjects' performance on the CCT may improve even more significantly after a period of adjustment with the modified earmolds. The theory of acclimatization (Gatehouse, 1992, 1993) suggests that the auditory system needs time to adjust, or acclimate, to a new signal in order to maximize the information presented. With time and use of the acoustically-tuned earmolds, S3 may have performed better and preferred the acoustically-modified earmold over the earmold with #13 tubing. This issue needs further investigation.

Summary

In summary, for these three cases, the CFA earmolds fell dramatically short of the reported advertised values of 20 dB of additional gain for the high frequencies. Nevertheless, there was a substantial increase in gain for frequencies above 2000 Hz when compared to the earmold with the standard #13 tubing. Similarly, the Libby horn earmolds provided a high frequency "boost," especially at 3000 to 4000 Hz, over the standard #13 tubing earmold and the CFA earmolds. Each tubing modification offers some advantages over the other. For example, tubing

changes are easier with the CFA earmolds, requiring a simple removal of the tubing at the elbow rather than removal of the tubing within the canal section of the earmold. The particular use of one acoustically-modified earmold over the other may be dependent on factors such as potential acoustic feedback, size limitations of the ear canal, ease of tubing change, and/or the individual's acoustical system. Regardless of which earmold modification is chosen, for individuals with hearing impairments that need additional emphasis in the high frequencies, acoustically-tuned earmolds should continue to be strongly considered. From the authors' clinical experiences, there does not appear to be any contraindications for use of acoustically-tuned earmolds.

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