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Acoustic Versus Electronic Modifications of Hearing Aid Low-Frequency Output*

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ABSTRACT

The rated quality and intelligibility of speech processed by hearing aids in which the low-frequency output had been reduced by either electronic modification (low-cut tone controls) or acoustic modification (vented or open earmolds) was investigated. Fifteen subjects with high-frequency hearing loss provided data for nine commercial hearing aids and both high and low background noise levels. Results for both background noise levels indicated that for hearing aids with a low-frequency cut off at or above 750 Hz (as measured in this investigation), the use of a vented or open earmold significantly improved both quality and intelligibility even when it had essentially no effect on the hearing aid's low-frequency output. The implication of the outcome is that for an individual with essentially normal low-frequency sensitivity and a high-frequency hearing loss, an earmold incorporating an opening should be used whenever possible, even though it may not be used for the purpose of controlling low-frequency amplification.

Individuals with relatively good low-frequency sensitivity and a high-frequency hearing loss usually are fitted with an amplification system which emphasizes high-frequency sounds to some extent. In the past, the requirement of a relative reduction of low-frequency amplification was usually accomplished acoustically through the employment of vented or open earmolds. In more recent years, technological advances have resulted in hearing aids which have the capability of varying low-frequency amplification using electronic modifications incorporated within the hearing aid; namely, low-cut tone controls. At the present time, therefore, an amplification system with a relative high-frequency emphasis can be obtained using several different types of low-frequency modification. The three which were studied in this investigation could be characterized as follows:

Type I: Reduction of low-frequency output using a low-cut tone control. When it is combined with a closed earmold, this modification is entirely electronic.

Type II: Choosing a hearing aid which would, in a closed system, deliver more low-frequency energy than desired and reducing low-frequency output by coupling the instrument to a vented or open earmold. As long as the hearing aid is electronically configured to deliver its broadest frequency response (i.e., either there is no tone control or it is not used), this modification is entirely acoustic.

Type III: A combination of types I and II. In this method, low-frequency output is reduced by adjustment of the low-cut tone control. In addition, the hearing aid is coupled to a vented earmold which may, or may not, result in further low-frequency reduction. This results in combined acoustic and electronic modification effects.

However, there are certain inherent differences between acoustic and electronic modifications of low-frequency output: they do not produce identical changes in the hearing aid's frequency response. Activation of a low-cut tone control switch results in a predictable decrease in output level below a known cutoff frequency. By contrast, substitution of a parallel vented or open earmold for an unvented earmold results not only in a drop in low-frequency output, but also in midfrequency resonance effects.[3] Also, the exact frequencies or magnitude in decibels of these effects for a given individual cannot accurately be predicted in advance. In addition, if a vented or open earmold is used, unamplified sound may enter the ear canal through the earmold opening so that the listener is exposed to an unpredictable mixture of amplified and unamplified signals.[5] This cannot occur when a closed earmold is used.

It would appear, therefore, that unless acoustic modification of low frequencies results in a hearing aid-processed signal which is more intelligible and/or more pleasing than that resulting from electronically controlled low frequencies, electronic modification alone must be the method of choice because it produces more predictable changes and, when combined with a closed earmold, results in fewer problems with acoustic feedback.

As a result of these considerations, an investigation was performed to determine whether acoustic and electronic methods of modifying low-frequency output have equiva-

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lent subjective effects as long as they result in frequency responses which are essentially identical except for the inherent differences described above (the inherent differences, of course, cannot be avoided).

The specific research questions follow. (1) Do individuals with primarily high-frequency hearing loss perceive statistically significant differences between hearing aid-processed speech samples which have been modified either acoustically or electronically when both modification methods produce equivalent frequency response curves (except for the inherent differences)? (2) If significant differences due to modification methods are noted, do these differences interact with (a) hearing aid low-frequency cutoff, (b) background noise levels, or (c) type of judgement task (ratings of intelligibility, quality attributes, or overall preference)?

METHOD

These questions were investigated using a method of paired comparisons. Subjects were presented with pairs of stimuli consisting of two recordings of continuous discourse, both processed by the same hearing aid and differing only in the method employed for control of low-frequency output. In one sample of a pair, the hearing aid was coupled to a closed earmold and its low-frequency output was controlled by the adjustment of its low-cut tone control (the "electronically modified" condition). This was always a type I low-frequency modification as described above. In the other sample of the pair, the hearing aid was coupled to a vented or open earmold and thus the low-frequency output was influenced not only by the hearing aid's electronic configuration but also by the acoustic effects of the earmold (the "acoustically modified" condition). This was either a type II or type III low-frequency modification as described above. The two samples of a pair had essentially identical frequency responses except for the inherent differences between acoustic and electronic modifications.

Hearing Aid Conditions

Nine commercial hearing aids were used in the study. All were performing according to manufacturer specifications. All had omnidirectional, front-facing microphones with peak clip limiting and low-cut tone controls. They were divided into three groups of three hearing aids each on the basis of the low-frequency cutoff in the electronically modified condition. For this investigation, low-frequency cutoff was determined from measurements of the hearing aid's performance in the simulated ear canal of a KEMAR manikin. Frequency/gain functions were measured with the hearing aids coupled to the manikin and adjusted as for the electronically modified condition. The manikin was located in an audiometric test room, 1 m from the loudspeaker. The input signal was a broadband white noise, at an overall sound pressure level of 65 dB, equalized to obtain an essentially uniform spectrum level in the sound field with the manikin absent. Signal azimuth was 0°. Measurements were made in ⅓ octave band levels. To determine the low-frequency cutoff, the level of the most intense ⅓ octave band was noted and a horizontal line was drawn on the frequency/gain function 30 dB below this level. The left-most intersection of this line with the frequency/gain function was taken as the low-frequency cutoff. Analogous frequency/gain functions were also measured with the hearing aids coupled to the manikin and adjusted as for the acoustically modified condition. However, these were not used to determine the low-frequency cutoff.

Figure 1 shows frequency/gain functions from the first group of hearing aids. This group was defined as having low cutoff frequencies lower than 750 Hz. The actual low cutoff frequencies were 330, 500, and 600 Hz. The figure shows the frequency/gain functions, measured in ⅓ octave bands, of the two tone control/earmold configurations used with each hearing aid. The solid line shows the spectrum measured in the ear canal of the manikin for the electronically modified condition (a type I modification). The dotted line shows the spectrum measured in the acoustically modified condition. For this group of aids, the acoustic modification consisted of an earmold with a large parallel vent (a type II modification). The two frequency/gain functions for a given hearing aid were considered equivalent when the levels in each ⅓ octave band were within 2 dB except for the resonance region associated with the vent. This resonance is seen in these examples as a relatively broad region around 1000 Hz in which the dotted curve rises above the solid curve. For each hearing aid, the low-frequency cutoff is indicated with an open circle on the solid curve.

Figure 2 shows the frequency/gain functions from the second group of hearing aids. This group was defined as having low cutoff frequencies in the range 750 Hz to 1000 Hz. Actual low cutoff frequencies were 750, 910, and 920 Hz. Again, the solid line shows the spectrum measured in the manikin's ear canal for the electronically modified condition (type I modification) and the dotted line shows the spectrum measured in the acoustically modified

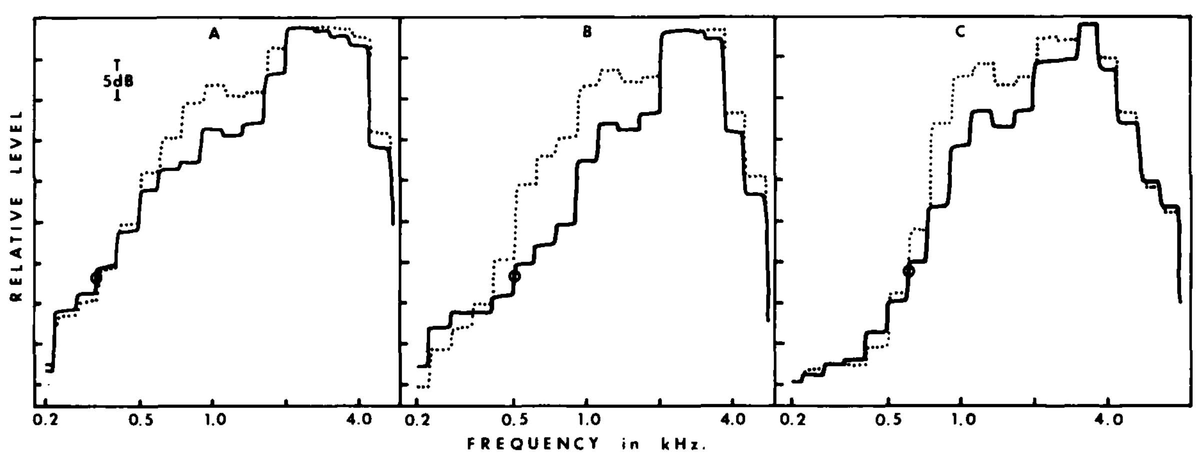

Figure 1. Frequency/gain curves, measured in one-third octave band levels, of the two tone control/earmold configurations used with each hearing aid from the first group of instruments. This group was defined as having low cutoff frequencies below 750 Hz. *Solid lines* depict the electronically modified condition. *Dotted lines* show the acoustically modified condition. *Open circles* indicate the derived low cutoff frequency for each instrument.

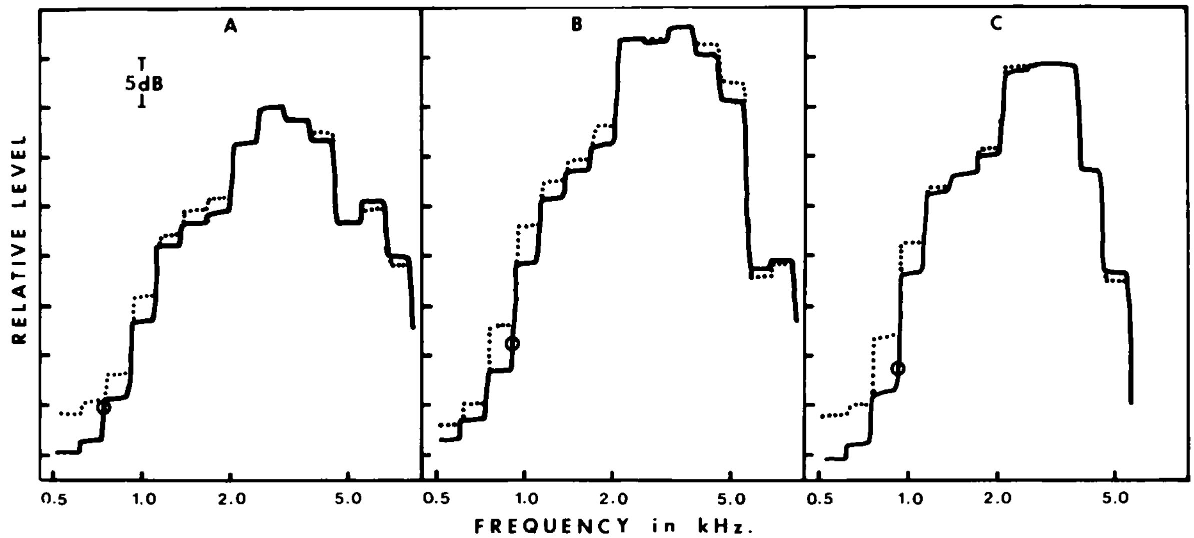

Figure 2. Frequency/gain curves, measured in one-third octave band levels, of the two tone control/earmold configurations used with each hearing aid from the second group of instruments. This group was defined as having low cutoff frequencies between 750 Hz and 1000 Hz. *Solid lines* depict the electronically modified condition. *Dotted lines* show the acoustically modified condition. *Open circles* indicate the derived low cutoff frequency for each instrument.

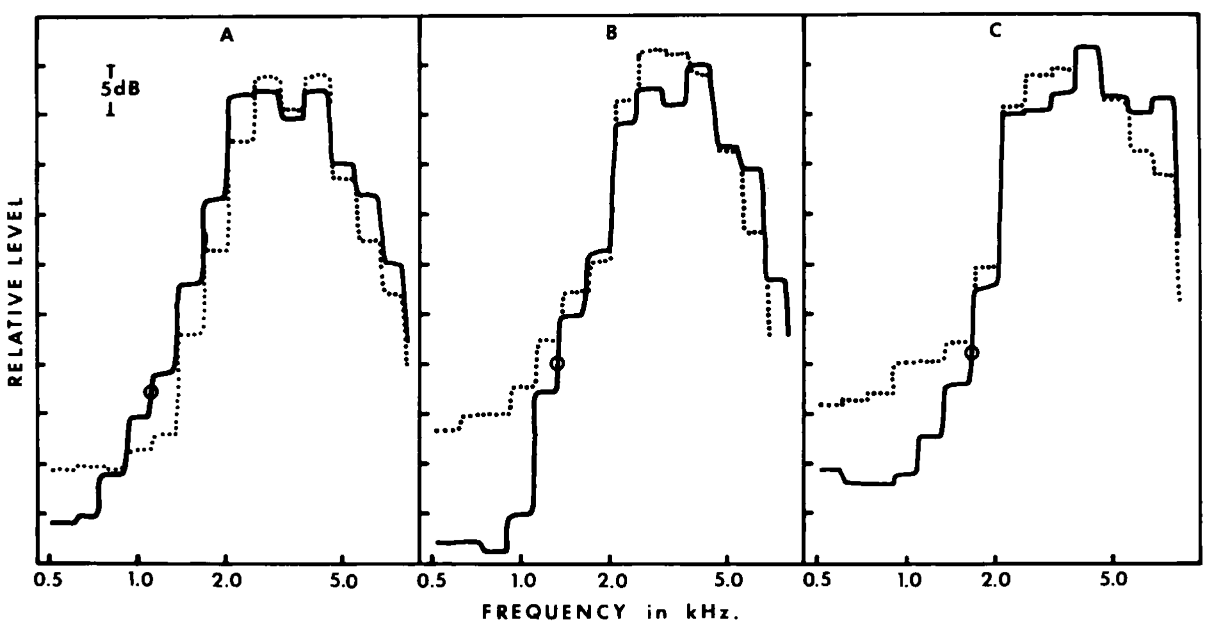

Figure 3. Frequency/gain curves, measured in one-third octave band levels, of the two tone control/earmold configurations used with each hearing aid from the third group of instruments. This group was defined as having low cutoff frequencies above 1000 Hz. *Solid lines* depict the electronically modified condition. *Dotted lines* show the acoustically modified condition. *Open circles* indicate the derived low cutoff frequency for each instrument.

condition. In this group of aids a type III acoustic modification was used. That is, an earmold with a large parallel vent was added to the electronic low-frequency reduction which had been used to achieve the electronically modified condition. A comparison of these two long-term average spectra reveals very little difference between them. Perhaps surprisingly, the only effect of adding the vented earmold was a very slight increase in low-frequency level, probably resulting from the vent-associated resonance around 1000 Hz. However, the absolute magnitude of this effect was quite small. The vent in the earmold had almost no effect on the output of the hearing aids because the frequency region in which the vent was effective was lower than their low cutoff frequencies.

Figure 3 shows the frequency/gain functions from the third group of hearing aids. This group was defined as having low cutoff frequencies above 1000 Hz. Actual low cutoff frequencies were 1100, 1310, and 1650 Hz. Again, the solid line shows the spectrum measured in the manikin's ear canal for the electronically modified condition (type I modification) and the dotted line shows the spectrum measured in the acoustically modified condition. In this group of aids, a type II acoustic modification was used; that is, each hearing aid was set to provide its broadest frequency response and then coupled to an open earmold. Use of an open earmold had two noteworthy effects. First, unamplified signals in the lower frequency region gained direct access to the ear canal through the earmold opening. This effect is seen in all the hearing aids but is less pronounced in A than in B or C. Second, when the closed earmold was used, shortening the ear canal, the ear canal resonance (which contributed to the signal level) occurred in the 7000 Hz region. When the open earmold was used, restoring the ear canal to its usual length, this resonance disappeared and was replaced by a more typically located ear canal resonance in the 3000 Hz region.

Subjects

Fifteen adults (nine males, 6 females; mean age: 54.8 yrs; age range 21 to 80 yrs) with relatively normal low-frequency sensitivity and a sloping mild to moderately severe sensorineural high-frequency hearing loss in the better ear participated in this investigation. Individuals with this type of audiometric configuration were selected because they were prime candidates for high-frequency emphasis amplification according to current practice in hearing aid fitting. An audiogram depicting the range of hearing loss which was considered to be appropriate for the investigation is shown in Figure 4. The mean audiogram for the test ears of the subjects from this study is also shown on the figure. Eight of the 15 subjects were experienced hearing aid users (i.e., wore amplification for at least 4 hr each day), and 3 of the 15 subjects had previously participated in hearing aid research projects which utilized a paired comparison paradigm.

Selection of the subjects' test ears was determined by the following criteria: (1) if the subject's hearing loss was asymmetrical, the better ear was selected as the test ear; (2) if the hearing loss was symmetrical and the subject was an experienced hearing aid user, the normally aided ear was selected; and (3) for those subjects with symmetrical hearing loss and no hearing aid experience, the test ear was randomly selected. Seven left ears and eight right ears were used as the test ears.

Stimuli

Stimulus tapes were prerecorded in a sound-treated room with a KEMAR manikin wearing each of the nine experimental hearing aids. For each tone control/earmold configuration, a 2-min segment of continuous discourse at 65 dB SPL was recorded in the presence of a multitalker babble at +5 dB signal-to-noise ratio

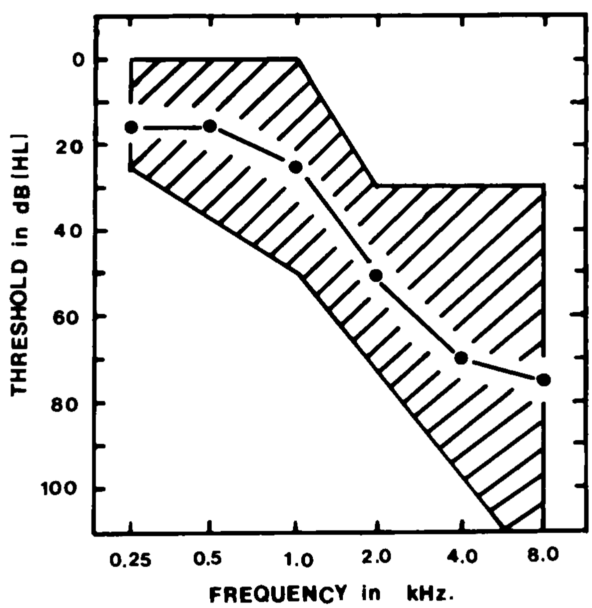

Figure 4. The *shaded area* depicts the range of hearing losses which was considered appropriate for the investigation. The *curve* shows the mean audiogram for the test ear of the 15 subjects.

CLEAR	: ___ : ___ : ___ : ___ : ___ : ___ :	BLURRED
FULL	: ___ : ___ : ___ : ___ : ___ : ___ :	THIN
NATURAL	: ___ : ___ : ___ : ___ : ___ : ___ :	UNNATURAL
NEAR	: ___ : ___ : ___ : ___ : ___ : ___ :	FAR
GENTLE	: ___ : ___ : ___ : ___ : ___ : ___ :	SHRILL
PLEASANT	: ___ : ___ : ___ : ___ : ___ : ___ :	UNPLEASANT

Figure 5. An illustrative example of the attribute rating score sheet used in the study. (On actual score sheets the vertical and horizontal arrangements of the positive and negative descriptor pairs were randomized.)

(S/N) and also at a +20 dB S/N. This continuous discourse sample was originally recorded in an anechoic environment by a male talker whose speech contained no identifiable regional characteristics. Both signal and background noise were presented from a single loudspeaker 1 m from the manikin at a 0° azimuth. The details of the recording and playback procedure were essentially as described by Cox and Studebaker[5] with the exception that, for this investigation, the modified earmolds were used in the recording phase instead of in the playback phase. With this procedure, the effects of the earmold changes were held constant across subjects. For playback, the prerecorded stimuli were transduced by a hearing aid receiver (Knowles BP 1712). All subjects wore standard unvented earmolds. The frequency response of the playback system was flat within ±1.5 dB from 100 Hz through 7000 Hz. Nine low-noise (+20 dB S/N) stimulus pairs and eight high-noise (+5 dB S/N) stimulus pairs were produced; a technical problem resulted in the elimination of the recording of the ninth high-noise pair. Each stimulus pair consisted of two recordings processed through a single hearing aid with either acoustic or electronic modifications of its low-frequency output. The amount of gain used with each hearing aid was the maximum amount of gain available in the acoustically modified condition without measurable suboscillatory feedback effects.[4] In the electronically modified condition, the gain was adjusted, if necessary, to be equal to that obtained in the acoustically modified condition.

Procedures

To present the paired comparison stimuli, the two prerecorded hearing aid-processed speech samples of a pair were aligned on two Revox A-77 tape recorders. The recorders were started synchronously and the outputs were directed to the subject via a control panel containing a two-position switch which allowed the subject to listen, at will, to the output from either tape recorder. The control panel also contained two attenuators which allowed independent adjustment of the loudness of each sample. It was stressed that the two samples should be adjusted for equal loudness. Subjects listened monaurally at their preferred listening levels.

Subjects rated each sample of a pair for several attributes (defined by bipolar word scales) related to the quality of the hearing aid-processed speech. The ratings were performed on equal-interval scales containing six intervals. An illustrative example of the attribute rating score sheet is shown in Figure 5. Four of the word pairs used to describe quality attributes were reported by Gabrielsson and Sjogren[8] to have high correlations with perceived sound quality of hearing aid-processed speech. These pairs were: clear versus blurred; full versus thin; near versus far; and gentle versus shrill. Two additional attributes (defined by pleasant versus unpleasant and natural versus unnatural) were also rated.

In addition, for each pair, subjects indicated which sample of the pair was more intelligible (more intelligible was defined as "having the highest proportion of understandable words") and also which sample of the pair they would prefer overall for their personal hearing aid, taking into account the intelligibility and the quality of the speech.

All subjects responded to all 17 pairs of stimuli.

Finally, to test the reliability of the outcome, the entire task was performed a second time on a different day by all subjects.

All experimental variables were counterbalanced or randomized to minimize order effects.

RESULTS

Statistical analysis revealed that there were no significant differences in attribute ratings or preference judgements between data obtained in the test and retest sessions. Therefore, all results were combined for subsequent analyses.

Attribute Ratings

For data analysis, the intervals along the six-equal-interval rating scales were assigned numerical values from 1 to 6 with the more positive descriptor assigned the high value. The higher the score for an attribute, the more positive the rating. The scored results indicated the degree of perceived differences between the modification methods. The data were analyzed using a six-factor analysis of variance [$3 \times (3) \times 6 \times 2 \times 2 \times 2$] with the following variables: hearing aid groups; hearing aids (nested within groups); attributes; modification methods; background noise levels; and test sessions.[17] Significant interactions were further investigated using a Least Significant Differences Modified post hoc analysis.[17] A detailed description of the results can be found elsewhere.[1]

A significant main effect was observed for modification methods ($p = 0.0001$). In addition, the interaction between hearing aid groups and modification methods was significant ($p < 0.0001$).

Figure 6 shows the mean ratings for the electronically modified and acoustically modified speech samples for the three hearing aid groups. These data include the results obtained from ratings of all six quality attributes in both high and low noise conditions in both test sessions. The ordinate shows the mean rating scores with higher numbers corresponding to more positive ratings. The abscissa shows the three hearing aid groups distinguished in terms of their low cutoff frequencies. The dashed bars show the mean ratings for the acoustically modified hearing aid-processed speech samples and the dotted bars show the mean ratings for the electronically modified samples. In evaluating these data, it is important to keep in mind that all pairs were comprised of two recordings from the same hearing aid. Different hearing aids were never compared directly with each other.

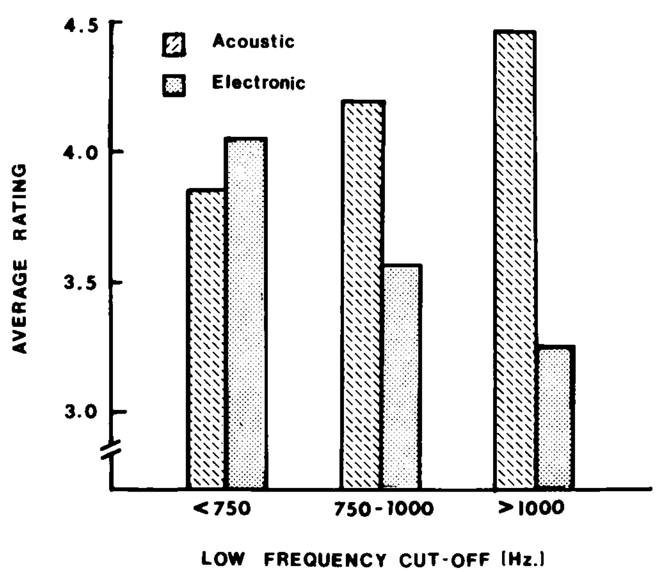

Figure 6. Mean quality attribute ratings for the electronically modified and acoustically modified speech samples for the three hearing aid groups. Higher numbers correspond to more positive ratings.

As Figure 6 shows, for the hearing aids with low-frequency cutoff less than 750 Hz, there was a slight overall preference for the quality of the electronically modified samples. The differences between the two conditions for this group of hearing aids was statistically significant at the 0.04 level.

For the hearing aids in the two groups with low cutoff frequency at or above 750 Hz, there was marked preference for the quality of the acoustically modified samples and this preference increased as low-frequency cutoff increased. These differences were statistically significant beyond the 0.001 level.

Six different attributes were rated because it was thought that some might prove to be more discriminating than others. However, the results on all attributes were essentially the same in the sense that a relatively high rating on one attribute was always associated with relatively high ratings on all the other attributes for that condition and vice versa. On the other hand, not all attributes yielded statistically significant differences between modification methods for every hearing aid. Table 1 summarizes these results. It should be noted that all the significant differences were in the expected direction. That is, in the instruments with cutoffs lower than 750 Hz, the electronically modified condition received the higher rating. In all other instruments, the acoustically modified condition was rated higher. If one attribute had to be selected as most discriminating it would probably be the attribute "near versus far." This attribute resulted in statistically significant differences between electronically modified and acoustically modified samples in eight of the nine hearing aids.

Low and high noise levels were included in this study because it seemed possible that an interaction with noise level would be seen. For example, acoustic modifications might be preferred for quality or intelligibility in low noise levels but electronic modifications might be preferred in high noise levels. However, this hypothesis was not supported by the data. The only effect of increasing the noise level was to decrease the absolute ratings in all conditions: the relative ratings of acoustic versus electronic conditions remained the same in all groups of hearing aids.

Finally, in spite of the variations which exist between commercial hearing aids, the three instruments within each group resulted in remarkably uniform data. This is seen in Figure 7, which shows the data in terms of the individual hearing aids ordered from left to right in terms of increasing

Table 1. Results of the attribute rating analysis

Attribute	Hearing Aid Low Cutoff Frequency (Hz)								
	330	500	600	750	910	920	1100	1310	1650
Clear/blurred				*			*	*	*
Full/thin				*	*	*	*	*	*
Natural/unnatural						*	*	*	*
Near/far		*	*	*	*	*	*	*	*
Pleasant/unpleasant			*				*	*	*
Gentle/shrill	*		*				*	*	*

* *Attributes which yielded significantly different ($p < 0.01$) ratings for acoustic and electronic modification conditions for each hearing aid.*

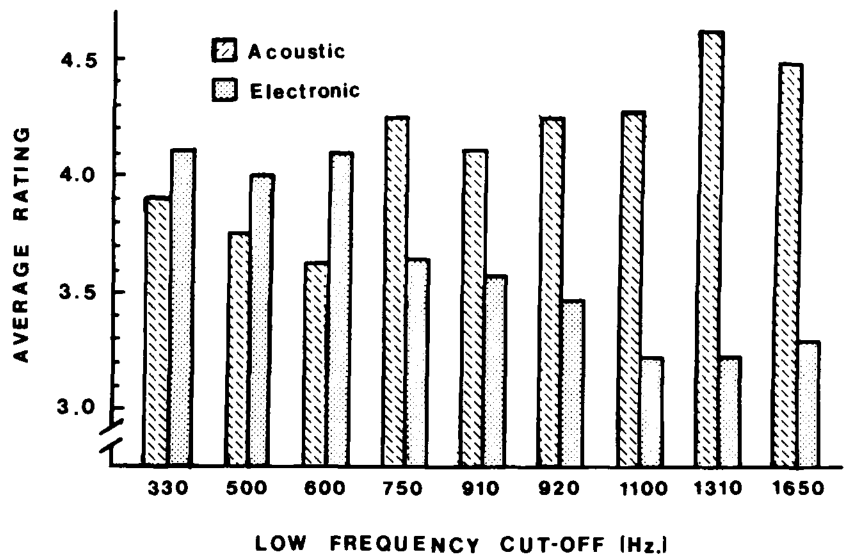

Figure 7. Mean quality attribute ratings for the electronically modified and acoustically modified speech samples for the individual hearing aids. Higher numbers correspond to more positive ratings. The hearing aids are ordered from left to right in terms of their low cutoff frequencies.

low-frequency cutoff. There is a clear trend for quality ratings to increase for the conditions using vented or open earmolds as the low-frequency cutoff of the hearing aids was increased. Conversely, the quality ratings decreased for the conditions using electronic modifications in combination with a closed earmold as the low-frequency cutoff of the hearing aids was increased.

Judgments of Intelligibility and Overall Preference

As noted earlier, subjects were asked to choose the most intelligible sample of each pair and also the sample which they would prefer as their personal hearing aid. These data were analyzed using the χ^2 test, and the McNemar test for the significance of changes.[16] The results showed exactly the same trends as seen in the quality ratings. In other words, if the hearing aid's low-frequency cutoff was higher than 750 Hz, the condition using a vented or open earmold was rated significantly more intelligible and was preferred in all ways over the condition using a closed earmold. In the hearing aids with low-frequency cutoff less than 750 Hz, there was a slight but significant preference for the closed earmold condition.

DISCUSSION

The outcome of this investigation provides a basis for a redefinition of the role of vented and open earmolds in hearing aid fittings. It is clearly no longer necessary to utilize openings in earmolds to control the low-frequency response of hearing aids: this can be done more effectively and predictably using the electronic controls available on many present-day instruments. However, the results reported here strongly suggest that for subjects with high-frequency hearing loss and normal or near-normal low-frequency sensitivity, the use of vented or open earmolds in combination with electronic control of low frequencies contributes significantly to the perceived intelligibility and quality of speech processed by the amplification system. This effect was evident for hearing aids with a low cutoff frequency of 750 Hz or more when measured as in this investigation. It should be noted that this low cut-off frequency would correspond approximately to a low-frequency cutoff of 500 to 600 Hz if the frequency range of the hearing aid were measured in the standard manner.[2]

For the group of hearing aids with low-frequency cutoff lower than 750 Hz, the quality and intelligibility of the hearing aid-processed speech signal were slightly better when the hearing aid was combined with a closed earmold. However, it should be kept in mind that the subjects in this investigation all demonstrated good low-frequency sensitivity. Therefore, it is unlikely that hearing aids from this group, with their relatively greater low-frequency gain, would be chosen for these subjects.

Although it appears evident that an opening in the earmold improves the perceived quality and intelligibility of the processed speech signal for hearing aids with relative high-frequency emphasis, this study does not provide information on how large an opening is necessary to achieve this effect. Perhaps a vent of a standard, moderate size could be used with satisfactory results on all high-frequency emphasis hearing aids.

Finally, the results of this investigation cast light on an apparent contradiction which has existed in the literature for some time surrounding the relationship between the quality of hearing aid-processed speech and low-frequency amplification. On the one hand, there have been persistent anecdotal reports in the literature that the use of vented or open earmolds to reduce low-frequency amplification results in improved sound quality. [6, 7, 9–12] On the other hand, numerous studies have reported that reduction of low-frequency content achieved by electronic modification results in a decrease in sound quality.[8, 13–15] The outcome of this study is consistent with both findings. This seems to indicate that a factor (or factors) other than the long-term average frequency response is needed to account for these findings. In any case, it does not seem adequate to account for the results of this study on the basis of a simple preference for the sample in each pair which contained the greater low-frequency content. For example, consider Figure 1. All three instruments revealed a relatively greater low-frequency output in the acoustically modified condition. However, the data indicate that the electronically modified condition was preferred for these hearing aids. In Figure 3, all three hearing aids show greater low-frequency output in the acoustically modified condition and the preference for this condition would seem to be consistent with a selection on the basis of low-frequency content. However, a close study of Figure 3A reveals that in this instrument the electronically modified condition provided the greater low-frequency output over a considerable range of the frequency/gain function. Nevertheless, the acoustically modified condition was preferred. In fact, the results for this hearing aid were essentially identical with those for the hearing aids shown in Figure 3, B and C. Finally, the hearing aids in Figure 2 show minimal differences between the two conditions of low-frequency modification. The differences which do exist are in the direction which would support the hypothesis that subjects chose the condition which supplied more low-frequency content. However, it seems unlikely that these small differences could account for the outcome in view of the apparent lack of effect of differences of even greater magnitude in the hearing aid in Figure 3A.

References

1. Alexander, G. C. 1982. Listener's preferences for acoustic and electronic modifications of a hearing aid's frequency response. Unpublished master's thesis. Memphis State University.
2. American National Standards Institute. 1976. American National Standard Specifications of Hearing Aid Characteristics. ANSI S3.22-1976, New York.
3. Cox, R. M. 1979. Acoustic aspects of hearing aid-earcanal coupling systems. Maico Monogr. Contemp. Audiol. **1** (3).
4. Cox, R. M. 1982. Combined effects of earmold vents and suboscillatory feedback on hearing aid frequency response. Ear Hear. **3**, 12–17.
5. Cox, R. M., and G. A. Studebaker. 1980. Problems in recording and reproduction of hearing-aid-processed signals. pp. 169–195. *in* G. A. Studebaker, and I. Hochberg, eds. *Acoustical Factors Affecting Hearing Aid Measurement and Performance.* University Park Press, Baltimore.
6. Davis, R., and S. Green. 1975. The influence of controlled venting on discrimination ability. Hear. Aid J. **27** (5), 6, 34–35.
7. Dodds, E., and E. Harford. 1968. Modified earpieces and CROS for high frequency hearing losses. J. Speech Hear. Res. **11**, 204–218.
8. Gabrielsson, A., and H. Sjogren. 1979. Perceived sound quality of hearing aids. Scand. Audiol. **8**, 159–169.
9. Hodgson, C., and C. Murdock. 1970. Effect of the earmold on speech intelligibility in hearing aid use. J. Speech Hear. Res. **13**, 101–114.
10. Jetty, A. J., and W. F. Rintlemann. 1970. Acoustic coupler effects on speech audiometric scores using a CROS hearing aid. J. Speech Hear. Res. **13**, 290–297.
11. McClellan, M. E. 1967. Aided speech discrimination in noise with vented and unvented earmolds. J. Aud. Res. **7**, 93–99.
12. Northern, J. L., and K. W. Hattler. 1970. Earmold influence on aided speech identification tasks. J. Speech Hear. Res. **13**, 162–172.
13. Punch, J. L., and E. L. Beck. 1980. Low frequency response of hearing aids and judgements of aided speech quality. J. Speech Hear. Disord. **45**, 325–335.
14. Punch, J. L., A. A. Montgomery, D. M. Schwartz, B. E. Walden, R. A. Prosek, and M. T. Howard. 1980. Multidimensional scaling of quality judgements of speech signals processed by hearing aids. J. Acoust. Soc. Am. **68**, 458–466.
15. Schwartz, D. M., J. L. Punch, A. A. Montgomery, C. A. Parker, M. T. Howard, B. E. Walden, and R. A. Prosek. 1979. Electroacoustic correlates of hearing aid quality judgements. Paper presented at the Annual Convention of the American Speech and Hearing Association, Atlanta.
16. Siegel, S. 1956. *Nonparametric Statistics for the Behavioral Sciences.* McGraw-Hill, New York.
17. Winer, B. J. 1971. *Statistical Principles in Experimental Design.* pp. 514–577. McGraw-Hill, New York.

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