SIDE BRANCH AND PARALLEL VENT EFFECTS IN REAL EARS AND IN ACOUSTICAL AND ELECTRICAL MODELS

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ABSTRACT

The purpose of the project was to demonstrate and explain the acoustic effects of side branch and parallel vents in individual real ears. It was shown that parallel and side branch vents produce similar low frequency filtering effects and vent-associated reactance resonances. However, when the input system incorporates a side branch vent the sound pressure produced in the ear canal at frequencies above the vent-associated resonance is less than that produced when the input system is unvented. This effect is not seen when the input system is associated with a parallel vent. Data obtained in the real ear canals were compared to analogous measurements made using an acoustical model (the Zwislocki coupler) and an electrical model designed to simulate the hearing aid receiver, input tubing, earmold, ear canal, and eardrum. Both models yielded data very similar to the real ear results. The advantages of each model in predicting the effects of individual earmold vents are discussed.

Earmold vents have been used in the fitting of hearing aids for at least 30 years (Berger, 1970). For the most part, the purpose of introducing a vent into the earmold has been to provide a high pass filter effect, attenuating troublesome low frequency energy. However, the precise acoustic effects of earmold vents in real ears have always been difficult to predict and difficult to measure. In fact, as Lybarger stated in 1967, under some circumstances, vent holes introduced into an earmold for the purpose of reducing low frequency energy may have the opposite effect, actually enhancing the output in some low frequency regions. Because of the uncertainty regarding the in-use acoustical effects of earmold vents, some investigators proposed that modifications in the circuitry of the hearing aid would be a preferable method of reducing low frequency output (Watson and Tolan,1949; Lybarger, 1967).

The acoustic effects of various earmold vents

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obtained when the earmold is mounted on a simple cylindrical metal coupler have been studied by many investigators (for example, Cooper et al., 1975; Sung et al., 1975; Studebaker and Zachman, 1970; Lybarger, 1975; Cooper and O'Malley, 1975). A few investigations have been reported in which the effects of earmold vents, usually averaged across several subjects, have been measured in real ear canals (McDonald and Studebaker, 1970; Weatherton and Goetzinger, 1971; Studebaker and Zachman, 1970; Lybarger, 1975; Studebaker et al., 1976). In most of these investigations, attention was given to the dimensions of the vent, particularly the vent diameter.

The effect of changing the vent diameter upon the associated low frequency roll-off and resonant frequency has been studied in some detail. However, an aspect of venting which has received relatively little attention by researchers is the effect of the relationship between the vent configuration (i.e., side branch or parallel) and the other components of the sound transmission pathway. Another aspect receiving little attention is the effect of vents on the frequency region above the vent-associated resonance. Our results show this area to be significantly affected by vents of some designs. Two investigations (Cooper and O'Malley, 1975; Cooper et al., 1975) utilized parallel and side branch vents in

the research protocols. In both studies the authors observed some differences between the effects of the two vent configurations, particularly in the high frequencies. However, neither study was focused directly on the differences between the two vent configurations and the reasons for the observed differences were not thoroughly explored.

An ultimate goal of earmold acoustics research is to provide the clinician with information that will permit quantitative control over the effects of earmolds and earmold modifications on an individual basis. An essential step toward this goal is the development of a theoretical basis which is adequate to predict the major significant effects of earmold modifications. In this context model building and testing serves two useful purposes. First, it provides a means of testing the adequacy of theoretical explanations of a given level of complexity and, second, it provides a basis for the development and construction of devices or procedures that may have clinical utility in the prediction of earmold modification effects.

The purpose of the project described below was to demonstrate and explain the acoustic effects of side branch and parallel vents in individual real ears and the Zwislocki "ear-like" coupler. To assist in the explanation of the outcomes, an electrical model of the acoustic system was constructed and tested. On the basis of the results, suggestions are made regarding the selection of venting in the fitting of hearing aids.

Instrumentation and Procedures

Individual earmolds were fabricated for each of three ears (two ears of one subject and one ear of a second subject). Three bores were drilled in each earmold: (1) a signal input channel, the "main bore" of the earmold: (2) a bore parallel to the main bore to accommodate the tube of the probe microphone; (3) a vent of either parallel (Fig. 1A) or side branch (Fig. 1B and 1C) configurations. The resulting earmolds and the dimensions of the main bores and vents of each are shown in Figure 1.

Data were collected and analyzed by the noise subtraction method, a method which utilizes spectral analysis of broad band signals and permits the addition and subtraction of the derived spectra. This method has been fully described elsewhere (Studebaker, 1975, 1976).

The acoustical input signal was provided by a Bruel and Kjaer "button" type receiver, driven by a white noise signal from a General Radio random noise generator, type 1382. A 37-mm length of polyethylene tubing (internal diameter, 1.4 mm) was attached to the receiver and coupled to the earmolds as shown in Figure 1.

All earmolds were used in both vented and standard, unvented forms. Each earmold was converted from the vented form into the standard, unvented form by plugging the vent bore at its medial end or at its intersection with the main bore using modeling clay.
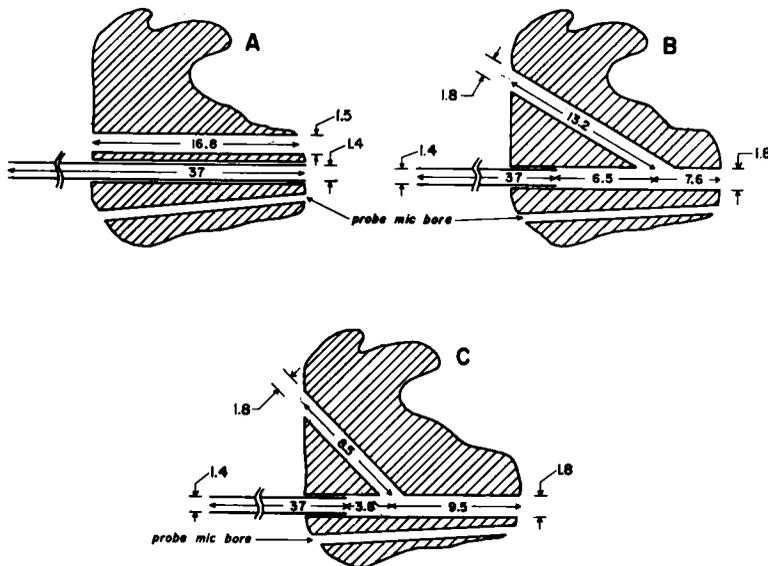
A battery-powered probe tube Knowles XL-9073

Fig. 1. Schematic representation of the earmolds used in the investigation. Earmold A is parallel-vented and earmolds B and C are side branch-vented. Dimensions (in millimeters) of the main bore, vent, and input tubing are shown for each earmold. The bore accommodating the tube of the probe microphone is also shown.

microphone was used to measure sound pressure in the ear canal. The microphone was attached to a 32-mm length of polyethylene tubing. Measurements were always made with the end of the tubing extended $3-5$ mm beyond the earmold tip. The signal from the probe microphone was delivered to a filter-amplifier constructed from two Burr Brown UAF-31 filters with a nominal cut-off frequency of 90 Hz and a low frequency roll-off of 20 dB/octave. The amplified signal was delivered to a Nicolet 440A real time analyzer which provided an averaged (over time) spectral analysis of the signal. The generated spectrum was then transferred to a Nicolet 1072 signal averager which was used to obtain the difference (in dB) between the averaged spectra obtained under the vented and unvented conditions. The vented and unvented response curves were thereby compared at 400 points along the frequency spectrum spaced at 12.5-Hz intervals between 0 Hz and 5 kHz. A hard-copy read-out of the results was obtained using an X-Y recorder.

Measurements in the Real Ear Canal. In measuring the acoustical effects of a particular vent in the ear canal of a particular person, two averaged spectra were generated: the spectrum of the broad band input signal at a point in the ear canal when the standard earmold was used, and the spectrum of the same signal at the same point in the ear canal when the vented earmold was used. In all measurements made using standard earmolds, considerable care was taken to ensure that a very good acoustical seal was obtained. The standard earmold spectrum was subtracted from the vented earmold spectrum using the signal averager, revealing the effect of the vent on the sound transmission characteristics of the input system, coupled to the ear of the individual subject.

Measurements Using the Acoustical Model. A Zwislocki coupler (Zwislocki, 1970) was used as an acoustical model of the ear canal-eardrum. Measurements made using this model followed the same protocol as described above for the real ear measurements, with the exception that the Zwislocki coupler was substituted for the real ear. As a matter of convenience, some measurements in the coupler were made using the coupler microphone rather than the probe microphone, after previous work had demonstrated that this change in procedure did not cause any changes in the relative (i.e., vented versus unvented) data.

Measurements Using the Electrical Model. An equivalent circuit simulating the hearing aid receiver diaphragm, the sound input tubing, the earmold and its vents, and the ear canal and eardrum was constructed from passive electronic elements in the configuration shown in Figure 2, wherein the circuit elements have the following acoustical analogs:

R_R = resistance of receiver diaphragm
L_R = inertance of receiver diaphragm
C_R = compliance of receiver diaphragm
C_{RV} = compliance of volume over receiver diaphragm
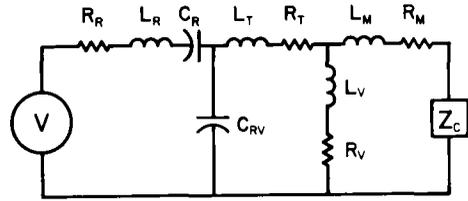L_T = inertance of sound input tubing, lateral to vent

Fig. 2. Diagram of the lumped parameters electrical model of the receiver sound input system-ear canal-eardrum used in the investigation. See "Instrumentation and Procedures" for definitions of symbols.

R_T = resistance of sound input tubing, lateral to vent
L_V = inertance of vent bore
R_V = resistance of vent bore
L_M = inertance of earmold main bore, medial to vent (for a parallel vent, $L_M = 0$)
R_M = resistance of earmold main bore, medial to vent
Z_C = impedance of ear canal plus eardrum

The form of the circuit representing the acoustical components of the receiver was derived from the work of Wansdronk (1962). The initial values of capacitance, inductance, and resistance used for the receiver were also taken from Wansdronk's work, but a variety of values were used subsequently to produce "receivers" of various frequency bandwidths and degrees of damping. The exact values of the components used in the receiver proved to have little effect on the vented-unvented comparisons which form the basis of this paper. The ear canal-eardrum impedance which terminated the circuit was usually the electrical analog of the Zwislocki coupler (Zwislocki, 1970).

The electrical values of the inductors and resistors which represent the earmold bores and vents in the electrical circuits were derived as follows: the length and diameter of the sound input bore or the vent of a particular earmold were measured. From these values the acoustic reactance and resistance values were calculated. Finally, these results were converted into analogous electrical reactance and resistance values. Inductors and resistors with the calculated values were inserted into the circuit at the appropriate locations and the effects on frequency response of the model were measured.

The electrical model of the "hearing aid receiver" was driven by the white noise output from the random noise generator. The resulting signal developed across Z_C was delivered to the real time analyzer. Spectra were obtained with the values of the earmold model adjusted to simulate, first, a standard earmold and second, a vented earmold of particular dimensions. The spectra were transferred to the signal averager where differences between the "standard earmold" spectrum and the "vented earmold" spectrum were obtained. The resulting curve, representing the effect of the simulated vent on the voltage developed across Z_C (the analog of the sound pressure developed in the ear canal), was printed out using the X-Y recorder.

Results

For each of the three vented earmolds studied, three separate curves were generated: (1) the effect of the vent measured in the real ear, (2) the effect of the same vent measured on the acoustical model (the Zwislocki coupler), and (3) the result when the vent was simulated on the electrical model. The results for each of the three vents studied are shown in Figures 3, 4, and 5. All data are shown with the vented earmold results plotted relative to the standard earmold results. Each figure shows the results for a given vent measured on the real ear (*solid line*), on the acoustical model (*dotted line*), and as simulated on the electrical model (*dashed line*).

In Figure 3, showing the effect of the parallel vent, all three data curves show the expected reduction in low frequency levels, and a vent-associated reactance resonance between 300 and 700 Hz. At frequencies above the vent-associated resonance, the pressure or voltage level remained equal to, or slightly higher than, the level when the standard earmold was used at all measured frequencies. At no point do the three curves differ by more than 3.5 dB and rarely by more than 2.5 dB.

In Figure 4, showing the effect of the side branch vent in Figure 1*B*, all three data curves show a low frequency reduction below 400 Hz

and a vent-associated reactance resonance between 400 and 800 Hz. Above the vent-associated resonance there was a decreased pressure or voltage level in the vented earmold condition which reached a maximum of 3-5 dB at about 3000 Hz for all three curves. The three results seldom differed by more than 3 dB.

In Figure 5, showing the effect of the side branch vent in Figure 1*C*, all three curves show the same loss of low frequency levels and vent-associated reactance resonance. Above 700 Hz, in the real ear data, there was a decrease in level observed in the vented earmold condition. The maximum decrease in level (10-11 dB) occurred in the frequency range between 2000 and 3000 Hz. Unlike previous results these data show an irregular pattern of peaks and valleys from 1500 to 4000 Hz. Data obtained from both the acoustical and electrical models also reveal decreased levels at frequencies above the vent-related resonance in the vented earmold condition. In both models the decrease began at about 600 Hz, whereas in the real ear it began at 750 Hz. In the acoustical model the maximum drop in level (9 dB) occurred at 3000 Hz, and there were irregular peaks and valleys in the data between 2000 and 4000 Hz. In the electrical model, the data formed a relatively smooth curve from 1500 to 4000 Hz. Results from the real ear were above those from the models by about 2-3 dB between
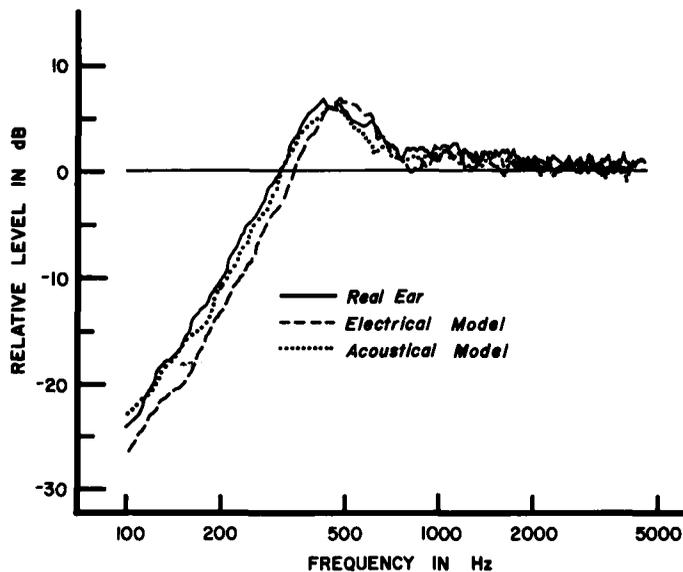

Fig. 3. Acoustical effect of the parallel vent shown in Figure 1*A*. Data showing the level of the signal in the real or modeled ear canal when the vented earmold was used are plotted relative to the level of the signal in the real or modeled ear canal when the standard (unvented) earmold was used.
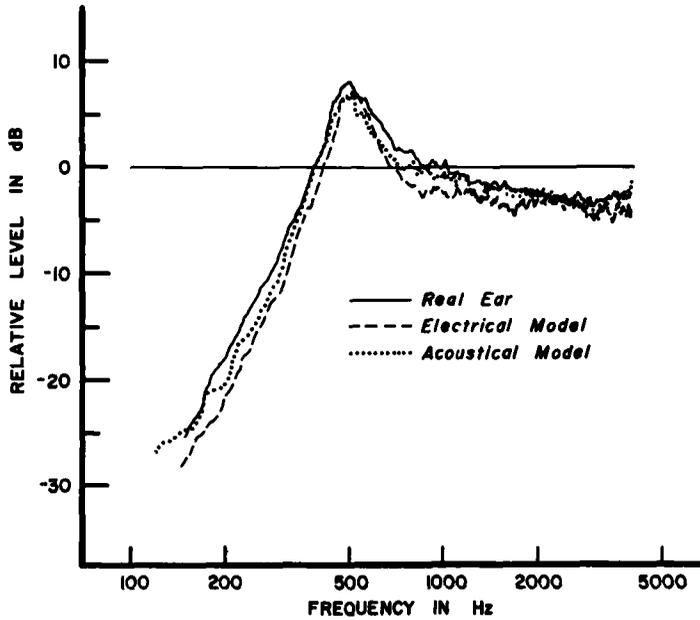
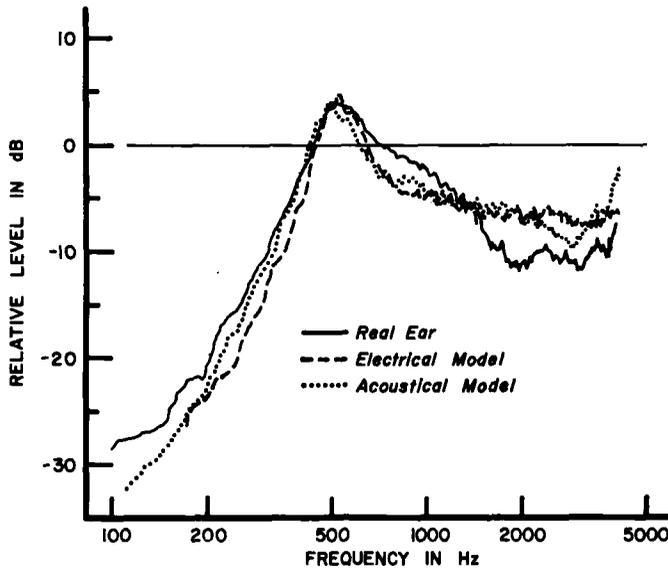Fig. 4. Acoustical effect of the side branch vent shown in Figure 1*B*.

Fig. 5. Acoustical effect of the side branch vent shown in Figure 1*C*.

700 and 1100 Hz but were lower than from the models by up to 4 dB between 1500 Hz and 4 kHz.

Discussion

Comparison of Parallel and Side Branch Vents. Examination and comparison of Figures 3, 4 and 5 show clearly that side branch and parallel vents produce similar low frequency filtering and vent-associated resonance effects. The low frequency effects of vents have often been modeled as shunt inductances to ground as they are in the electrical model shown in Figure 2. The similarity of the electrical model and the acoustical model and real ear results in Figures 3, 4, and 5 indicates that this modeling is quite adequate

for the lower frequency effects of both side branch and parallel vents on an individual earmold basis. The two side branch vents produced low frequency slopes which are very similar to each other and very slightly steeper than those seen with the parallel vent. The steepness of the low frequency rejection rates ranged from above 14 to 17 dB per octave; somewhere between that predicted by a two-pole and a three-pole high pass filter.

Studebaker and Zachman (1970) postulated that the resonant frequency of the vent-associated resonance was determined by the effective volume of air in the ear canal (or coupler) acting together with the earmold bore out to the vent plus the vent (or the vent alone in the case of parallel configuration) to form a series LC resonator. Based on this hypothesis, the calculated acoustic system resonant frequencies associated with each of the vents used in this study were 472 Hz for the parallel vent (Fig. 3), 511 Hz for the side branch vent in Figure 4, and 546 Hz for the side branch vent shown in Figure 5. (Because analogous L and C values are used in the electrical model the calculated values for it are very close to the same, within limits imposed by the values of readily available capacitors and inductors.) A comparison of these calculated values with those obtained reveals very good agreement in each instance, further supporting the Studebaker and Zachman hypothesis for both side branch and parallel vents.

Above the vent-associated resonance, the two vent types have quite different effects on frequency response. With side branch vents, a decrease was observed in the high frequency pressure levels reaching the eardrum, coupler microphone, or electrical circuit load relative to that seen with the standard earmold coupling. The reduction began at a frequency immediately above the vent-associated resonance and became progressively greater as frequency increased. On the other hand, when a parallel vent was used, no loss of level was observed (Fig. 3) at frequencies above the vent-associated resonance, and indeed, a slight relative increase in level was observed.

ᕀ It is hypothesized that the high frequency changes observed when side branch vents are used are attributable to the additive effects of two separate factors. First, the vent bore, in combination with that portion of the main earmold bore medial to the vent, plus the ear canal-

eardrum, acts as the acoustical equivalent of a current divider. The volume velocity at the vent-main bore intersection is divided in inverse proportion to the relative acoustic impedance of the vent bore versus the impedance of the remaining main bore plus that of the ear canal-eardrum. The higher the combined acoustical impedance of the main bore medial to the vent plus the ear canal-eardrum is relative to the acoustical impedance of the vent bore, the greater will be the proportion of the volume velocity shunted by the vent.

Bores and vents in earmolds behave as acoustic masses or inertances (Beranek, 1954, p. 131), and the impedance of each increases with increased frequency. In addition, the impedance of the eardrum (and its electrical analog) increases as frequency is increased (Zwislocki, 1970; Delany, 1964; Morton and Jones, 1956). As a result, the combined impedance of the two elements (the main bore medial to the vent and the ear canal-eardrum), rises at a faster rate with frequency than does the impedance of the vent bore alone. The proportion of the volume velocity diverted by the vent, thereby, increases as frequency is increased. As a result, volume velocity down the main bore decreases and the pressure level observed in the ear canal decreases progressively, as frequency is increased relative to the pressure observed in the closed earmold condition within the hearing aid's pass band.

When a parallel vent is used, division of the high frequency volume velocity does not occur before the ear canal is reached because there are no alternative pathways for the signal. Above the vent-associated resonance the vent's impedance is high and there is essentially no flow through it. Therefore, at these higher frequencies venting does not cause a reduction in level.

A factor of major importance in determining the extent of the loss of high frequency energy when a side branch-vented earmold is used is the ratio of impedances of the vent bore to that of the main bore plus ear canal-eardrum. This impedance ratio is primarily influenced by the relative lengths and diameters of the vent and that portion of the main bore medial to the vent-main bore intersection with greater length and smaller diameter each producing greater impedance. If the vent bore and the main bore are of the same diameter, as was true for the earmolds used in this study, then the relative impedances are determined primarily by the relative lengths of the

vent and main bore medial to their intersection. For any given diameters, the extent of the reduction in high frequency levels becomes greater as the vent intersects the main bore closer to the receiver, because this change reduces the vent length (and its impedance) while increasing the length (and impedance) of the main bore medial to the vent intersection. When the vent intersects the main bore very close to its receiver or lateral end the loss in sound level can become very substantial, reaching 15–20 dB or more, particularly if the vent has a large diameter. The reduction in level can extend downward in frequency as well to produce substantial reductions in level even in the resonance region. Conversely, as the side branch vent intersection is moved closer to the medial (ear canal) end of the main bore the loss of high frequency energy becomes smaller until the main bore length medial to the intersection drops to zero. A parallel vent is produced thereby and, as shown in Figure 3, the loss of high frequency energy also drops to zero.

The second factor involved in producing the high frequency effects observed when side branch vents are used is responsible for the series of resonance-like irregularities seen above 1.5 kHz in the results in Figure 5. Under most circumstances, the earmold main bore acts together with the sound input tubing, to produce wavelength resonances within the pass band of the hearing aid. When a side branch vent is introduced, an impedance discontinuity occurs at the intersection of the vent with the main bore, effectively dividing the main bore into two shorter lengths. As a result, the input tube wavelength resonances are shifted upward in frequency somewhat, the extent depending upon the exact position of the vent along the main bore. As a result, the observed irregular pattern of positive and negative differences emerges when side branch-vented earmold results are plotted relative to standard earmold results. The effect may be more or less pronounced, depending upon the extent of change in frequency location of the resonances. However, in practical terms, the extent of the shift in these resonances is slight and it probably does not have important consequences in most cases.

The wavelength resonances of the sound input system are not altered by the introduction of a parallel vent because the parallel vent does not intersect the sound input tube. Because the resonant frequencies are unchanged by the addition of the parallel vent, a smooth difference curve is obtained in the high frequencies as revealed in Figure 3. Hence, neither of the high frequency effects which operate when a side branch vent is used is a factor when a parallel vent is used. The pressure level in the ear canal at frequencies above the vent-associated resonance is not significantly influenced by the presence of an earmold vent if the vent is in a parallel configuration.

Comparison of Acoustical Model and Real Ear Results. The data reported in Figure 3 indicate that the effect of the parallel vent measured in the acoustical model (Zwislocki coupler) was within 2 dB of the effect measured in the real ear throughout the frequency range. For the side branch vent shown in Figure 4, the data obtained in the acoustical model were within 1 dB of the real ear results throughout the frequency range. Data for the other side branch vent (Fig. 5) show poorer agreement between the real ear and acoustical models, particularly at frequencies above the vent-associated resonance. The discrepancy in Figure 5 between the data obtained on the real ear and the acoustical model was principally caused by a failure of the vent to produce changes in the input system wavelength resonances between 1500 and 2000 Hz. Between 2500 and 4000 Hz the data curves for the real ear and the acoustical model follow an irregular but parallel course about 3 dB apart, indicating that, in this frequency region, the two curves are reflecting similar changes of resonance patterns.

In general, Figures 3, 4, and 5 reveal good to excellent agreement between the data obtained on real ears and the data obtained on the Zwislocki coupler in measuring the effect of parallel and side branch vents in all frequency regions studied. In a previous investigation (Studebaker et al., 1977), in which the effects of side branch vents were measured in real ears and in a Zwislocki coupler, it was observed that the slope of the low frequency filtering effect and the height of the resonance produced by the vent were different in the two measurement conditions. It was suggested in that paper that the observed differences were attributable to the presence of very small acoustical leaks which occurred when the standard earmold was fitted to the real ear in a normal "in-use" manner, but did not occur when the same earmold was affixed to the Zwislocki coupler. Subsequent observations substantiated that hypothesis. In collecting the data reported in this paper extraordinary care was taken to ensure that acoustical leakage was virtually eliminated

when measurements were made in the real ears with standard earmolds. The obtained data indicate that when this precaution is taken the results obtained from the real ear and the Zwislocki coupler are almost identical. However, this result also indicates that in order to replicate accurately the in-use seal of a standard earmold a calibrated leak should be built into the Zwislocki coupler to simulate the small leaks which occur around even well fitted typical earmolds.

Comparison of Electrical Model and Real Ear Results. Data from all three vents indicate that the electrical model-simulated vent produced somewhat more (2–4 dB) low frequency attenuation at frequencies below the vent-associated resonance than did the analogous vent in the real ear. The degree of agreement could be made nearly perfect by post hoc adjustment of the values of the electrical model, but the results reported here are those for the original unadjusted model values. The slope and general form of the low frequency filtering effect of the model and the location and amplitude of the vent-associated resonances very closely simulated the real ear results for all three vents, as Figures 3 through 5 reveal.

In the region above the vent-associated resonance, the data shown in Figure 3 indicate that the effect of the simulated parallel vent measured on the electrical model was within 2 dB of the effect of the real vent measured in the real ear. For the side branch vent shown in Figure 4, the loss of high frequency pressure in the vented condition was 2–3 dB greater in the model than the real ear between 700 and 2000 Hz. Above 2000 Hz, the electrical model gave results within 1 dB of the real ear results.

The data shown in Figure 5 for the second side branch vent indicate that, for this vent, the pattern of the loss of sound pressure in the vented condition above the vent-associated resonance was different for the electrical model from that in the real ear. The electrically modeled vent produced up to 3 dB more loss of pressure level from 650 to 1300 Hz and up to 4 dB less loss of pressure level above 1300 Hz than was produced by the analogous acoustical vent on the real ear.

The discrepancies noted between the real ear and the electrical model in the region above the vent-associated resonance are largely attributable to the wavelength resonance changes in the sound input channel discussed earlier. An inherent limitation in the use of a simple lumped parameter electrical model to simulate earmold

acoustical effects is, of course, the inability of such a model to portray effects which depend upon wavelength effects. Because, as discussed earlier, these wavelength resonances play a part in producing some of the effects of side branch vents, the electrical model will be inaccurate in simulating side branch vents to the extent that these resonances are a significant factor. Observations of the effect of side branch vents on several real ears have indicated that the extent of the wavelength resonance effects appears to be quite variable across different sound input system-side branch vent combinations and, therefore, constitutes a somewhat unpredictable element in the effect of the vent on a real ear. Inspection of the raw data curves indicated that the irregularities in the high frequency region of the acoustical side branch vent curves were produced by changes in the position of the input system resonances by a small fraction of their frequency location (i.e., 5–10%). Whether such changes are significant to the listener is doubtful.

It is of interest to note with regard to Figure 5, that the results obtained on the acoustical model tend to be more similar to the results obtained on the electrical model than to the real ear results. This may mean that the acoustical model does not produce changes in wavelength resonances in the same way, or to the same degree, as produced by real ears. Further study of this factor is required.

Comments Regarding Clinical Applications

Ultimately, the goal is to put in the hands of those who recommend vented earmolds the tools for estimating or predicting the effects of particular vents and configurations on the frequency response of a hearing aid worn by a particular person. The use of an electrical model to simulate the effects of vents of various configurations and dimensions proved to be highly flexible, easy to use and understand, inexpensive, and quite accurate. The acoustical model was somewhat more accurate, especially in the high frequencies, but is a less flexible, less easily manipulated, and more expensive device. Computer simulation of these effects would be highly flexible and versatile, but less widely available and more expensive. The choice of model depends upon issues such as whether the high frequency resonance shifts are significant, the importance of flexibility and, of course, cost. Final answers will require

further work but the simple lumped parameter electrical model appears to go a very long way toward predicting all of the essential effects of earmold venting.

The measurements reported here have shown that with certain vent constructions, it is possible to achieve an acoustical result which is completely opposite from the anticipated outcome. Vents, which are commonly thought to "simply" attenuate low frequencies while leaving high frequencies essentially unchanged, may instead result in increased low frequency and decreased high frequency output. The frequency range of the hearing aid with which the vented earmold is used is an important factor to consider in this regard. If, as is commonly the case, the hearing aid's frequency range does not extend much below, say, 300 Hz, many earmold vents will not produce a significant low frequency roll-off within the frequency range of substantial hearing aid output. On the other hand, the vent-associated resonance frequency (400–700 Hz), representing a region of increased output in the vented condition, will be located above the low frequency limit of the hearing aid's frequency range. In addition, if the vent is of a side branch construction, there will be a decrease in pressure reaching the eardrum at frequencies above the vent-associated resonance. The net result is an effective emphasis of low frequencies instead of the anticipated emphasis of high frequencies.

Because a decrease in high frequency output is almost never desired in the fitting of hearing aids, it seems advisable to avoid the use of side branch vents whenever possible. If the physical size of the earmold canal portion makes the use of a side branch vent inevitable, the vent should be drilled to intersect with the main bore of the earmold as close as possible to the tip of the earmold. This tactic will minimize the amount of high frequency energy loss and minimize resonance shifts.

A further point to consider in selecting a vent design is the limitation imposed by acoustical feedback. It is well known that the acoustical leakage from a vented earmold results in a lower threshold for acoustical feedback. The level at which acoustical feedback begins imposes an absolute limitation upon the amount of gain possible with a given hearing aid and earmold. Inasmuch as acoustical feedback in hearing aids is largely a high frequency phenomenon, it seems likely that more leakage (via the vent) of high frequency sound pressure would result in a lower threshold for acoustical feedback. Hence, it

would be anticipated that a side-branch vent would incur acoustical feedback at a lower gain setting than an "equivalent" parallel vent (i.e., one which produces the same low frequency filtering effect). This prediction is supported by the observation made by Angaard Johansen (1975) that the gain obtainable from a hearing aid before feedback set in was 12 dB less with a side branch-vented earmold than when a parallel-vented earmold was used.

In the practical selection of earmold vents, both physical and acoustical factors must be taken into consideration. Although physical limitations imposed by ear canal size favors side branch vents over parallel vents, all of the acoustical factors discussed mitigate against the use of side branch vents whenever possible. Both side branch and parallel vent constructions will result in a drop in the level of low frequency energy reaching the eardrum and in a vent-related resonance. However, the side branch construction also leads to loss of high frequency energy, complicated shifts in resonance patterns, and a lowered acoustical feedback threshold. The extent of all these undesirable effects can be minimized, in cases where use of a side branch vent is unavoidable, by drilling the vent so that it intersects the main bore at a point as close as possible to the medial tip of the earmold.

References

Angaard Johansen, P. 1975. Magnitude of the acoustical feedback as a function of leakage in earmoulds. Scand. Aud. [Suppl. 5] 271–279.

Beranek, L. L. 1954. *Acoustics.* McGraw-Hill Book Co., New York.

Berger, K. W. 1970. *The Hearing Aid: Its Operation and Development.* National Hearing Aid Society, Livonia, MI (Rev. Ed.).

Coogle, K. L. 1965. Is venting necessary? Natl. Hear. Aid J. **18**, 8–9.

Cooper, W. A., J. R. Franks, R. M. McFall, and D. P. Goldstein. 1975. Variable venting valve for earmolds. Audiology **14**, 259–267.

Cooper, W. A., and H. O'Malley. 1975. Frequency response characteristics of the positive venting valve for earmolds. Paper presented at American Speech and Hearing Association, Washington.

Delany, M. E. 1964. The acoustical impedance of human ears. J. Sound Vib. **4**, 455–467.

Lybarger, S. F. 1975. Comparison of earmold characteristics measured on the 2 cc coupler, the Zwislocki coupler, and real ears. Scand. Aud. [Suppl. 5] 65–85.

Lybarger, S. F. 1967. Earmold acoustics. Audecibel (Winter).

McDonald, F., and G. A. Studebaker. 1970. Earmold alteration effects as measured in the human auditory meatus. J. Acoust. Soc. Am. **48,** 1366–1372.

Morton, J. Y., and R. A. Jones. 1956. The acoustical impedance presented by some human ears to hearing aid earphones of the insert type. Acustica **6,** 339–345.

Studebaker, G. A. 1976. Further applications of the noise subtraction method. Paper presented at American Speech and Hearing Association, Houston.

Studebaker, G. A. 1975. A broad-band noise-based method of measuring frequency response. Paper presented at American Speech and Hearing Association, Washington.

Studebaker, G. A., R. M. Cox, and D. J. Wark. 1977. Earmold modification effects measured by coupler, threshold and probe techniques. Audiology (in press).

Studebaker, G. A., R. M. Cox, and D. J. Wark. 1976. The effect of earmold modifications measured by coupler, threshold and probe techniques. Paper presented at 92nd Meeting of the Acoustical Society of America, San Diego.

Studebaker, G. A., and T. A. Zachman. 1970. Investigation of the acoustics of earmold vents. J. Acoust. Soc. Am. **47,** 1107–1115.

Sung, R. J., G. S. Sung, and W. R. Hodgson. 1975. Acoustic influence of select-a-vent earmold and tone tube modification on hearing aid performance. J. Am. Aud. Soc. **1,** 15–20.

Wansdronk, C. 1962. On the mechanism of hearing. Phillips Research Reports Supplements. **62,** 1–140.

Watson, L. A., and T. Tolan. 1949. *Hearing Tests and Hearing Instruments.* Hafner Publishing Co., Inc., New York.

Weatherton, M. A., and C. P. Goetzinger. 1971. The effects of various modified earmolds on hearing sensitivity. J. Aud. Res. **11,** 25–32.

Zwislocki, J. J. 1970. An acoustic coupler for earphone calibration. Special Report. Laboratory of Sensory Communications, Syracuse University, Syracuse, NY.