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Hearing-Aid-Processed Signals: a New Approach[1]

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Key Words. Hearing aids · Hearing aid processing · KEMAR · Hearing aid selection

Abstract. A new protocol for obtaining and utilizing hearing-aid-processed signals in hearing aid research or hearing aid selection is described. Data are presented which illustrate the extent to which this procedure may be expected to result in a signal spectrum at the subject's eardrum which is the same as the spectrum the subject would have received if the hearing aid itself had been placed on his ear (a directly-aided situation). An earlier investigation by the authors indicated that the traditional protocol for the production and utilization of hearing-aid-processed signals results in substantial discrepancies between these two spectra. The data presented were obtained using the KEMAR as the subject with a Zwislocki coupler as the KEMAR's ear canal/eardrum. The discrepancy between directly-aided and hearing-aid-processed spectra was typically ±2 dB for ear-level hearing aids fitted using standard, vented, or open earmolds (in open earmold fittings only the amplified component of the directly-aided spectrum is reproduced).

In research protocols which involve the use of hearing aids on real subjects it has been often found convenient to prerecord the test signals through the hearing aids and to subsequently present the obtained 'hearing-aid-processed' signals to the subjects via an insert or supra-aural earphone.

The use of hearing-aid-processed signals in research or in hearing aid selection protocols usually contains the implicit assumption that the spectrum of the hearing-aid-processed signal arriving at the subject's eardrum is the same as the spectrum which would have occurred if the real hearing aid had been worn by the subject and the signal presented in the sound field in the

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usual way. The typical procedure for prerecording the test signal has been as follows: the signal is presented to the hearing aid situated alone in a sound field; the output of the hearing aid is delivered to a 2-cm^3 coupler and then recorded on magnetic tape; the tape-recorded signals are later presented to the experimental subjects via TDH-39 earphones mounted in MX-41/AR supra-aural cushions. It has been shown [*Cox and Studebaker,* 1977] that when this procedure is used the sound pressure at the subject's eardrum is less at frequencies below about 500 Hz (due to a leak under the MX-41/AR cushion) and greater in the region around 3 kHz (due to ear canal resonance effects) than the analogous sound pressure observed when the hearing aid itself is worn by the subject. In addition, it has been shown by many workers including *Studebaker et al.* [1977] and *Dalsgaard* [1977] that the spectrum of the signal impinging on a hearing aid microphone when the aid is placed alone in a sound field is different from the spectrum of the signal at the hearing aid microphone when the aid is placed on a head in that sound field. Furthermore, the extent and direction of this difference depend upon the orientation of the hearing aid's microphone and the azimuth of the signal source. It is clear, therefore, that the procedure described above for producing and utilizing hearing-aid-processed signals does not result in a signal at the eardrum which is spectrally similar to the signal provided when the hearing aid itself is worn.

The purpose of this paper is to describe a new method of producing hearing-aid-processed signals and to present data which indicate that when this method is used the hearing-aid-processed signal arriving at the subject's eardrum is very similar to the signal occurring at the eardrum when the hearing aid itself is worn. The approach was developed for use in a hearing aid selection procedure. However, the method is equally applicable to research involving hearing aids.

Rationale for the Procedure

The procedure in which each hearing aid is actually worn by the subject was conceptualized as shown in figure 1. Each block in the figure represents an element of the situation which shapes the acoustic signal during its transmission from the loudspeaker to the subject's eardrum. The goal of any alternative procedure must be to structure the situation in a way that results in the same spectrum at the subject's eardrum as obtained with the system described in figure 1.

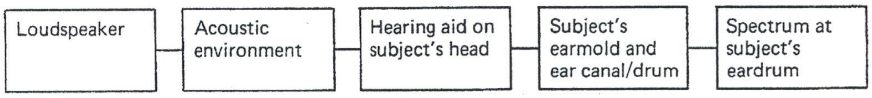

Fig. 1. Factors involved in a procedure in which each hearing aid is actually worn by the subject. Each block represents an element which may influence the acoustic characteristics of the signal during its transmission from the loudspeaker to the subject's eardrum.

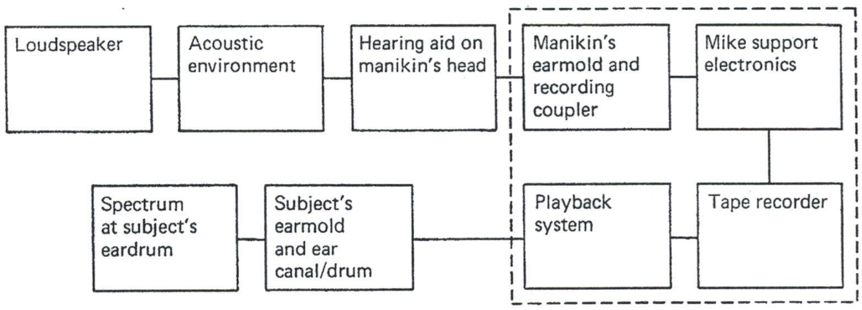

Fig. 2. Factors involved in a procedure in which the hearing aids are represented by prerecorded hearing-aid-processed signals. Each block represents an element which may influence the acoustic characteristics of the signal during its transmission from the loudspeaker to the subject's eardrum.

Figure 2 shows the conceptualization of a procedure in which the test material is pre-processed through the hearing aid worn by a manikin, stored on magnetic tape and subsequently presented to the subject via his individual earmold. If one assumes that the effect of the head (head diffraction, head baffle, etc.) on the sound field at the hearing aid microphone is the same for the manikin's head as it is for a real head (see below for a discussion of this point), it can be seen that the design goal for the system described in figure 2 must be for the elements enclosed within the dotted line to be collectively 'transparent', i.e., to have no net effect on the spectrum of the signal being processed by them. Since the process of recording and reproduction of a signal using high-quality tape and a properly adjusted tape recorder does not change the spectrum of the signal in the frequency range of interest, the recording coupler and the playback system are the main elements which must be made 'transparent'. In addition, the effect of the subject's earmold and ear canal/eardrum on the acoustic signal presented by the playback system must be the same as their effect on the signal presented by the original hearing aid. If these goals are achieved, the spectrum occurring at the subject's eardrum in the system described in figure 2 should be the same as the analogous spectrum in the system described in figure 1.

The Individually Fabricated Earmold

The importance of the individual earmold which couples the hearing aid to the ear canal has been recognized for many years [*Wansdronk,* 1962; *Ewertsen et al.* 1957; *Lybarger,* 1967; *Studebaker and Cox,* 1977; *Studebaker et al.,* 1976; *McDonald and Studebaker,* 1970; *Studebaker and Zachman,* 1970]. It is evident that the earmold influences the acoustic characteristics of the signal delivered to the ear canal from the hearing aid. The protocol for processing signals through hearing aids was therefore developed with the intention that the processed stimuli ultimately would be presented to the subject via his own individually fabricated standard, vented or open earmold.

Evaluation of the Manikin

The manikin used in developing this procedure was the KEMAR *(Burkhard and Sachs,* 1975]. The validity of the system described in figure 2 depends somewhat on the extent to which the baffle and diffraction effects due to the KEMAR's head are representative of the analogous effects due to real heads. To evaluate this factor a comparison was made between the head diffraction/baffle effects on hearing aid frequency response produced by the KEMAR and those produced by the heads of real persons. An ear level hearing aid was placed on the KEMAR and on each of 8 subjects. Figure 3 shows the hearing aid's output obtained with a 0° azimuth signal source. The results for the KEMAR are shown as the dotted line and the mean results from the 8 subjects are shown as the dashed line. The solid line at the bottom of the figure shows the difference between the two curves. The two curves are very similar across the entire frequency range and differ by more than 3 dB in only a few very narrow high-frequency regions. These data were obtained in a sound-treated audiometric test room such as is typically used in clinics for hearing aid selection procedures. Similar comparisons were made using another hearing aid and different acoustic environments. All comparisons yielded results essentially identical to those shown in figure 3.

The Manikin's Earmold

In this procedure, the KEMAR's earmolds are individually fabricated, standard (closed) earmolds with canal portions terminating at the entrance

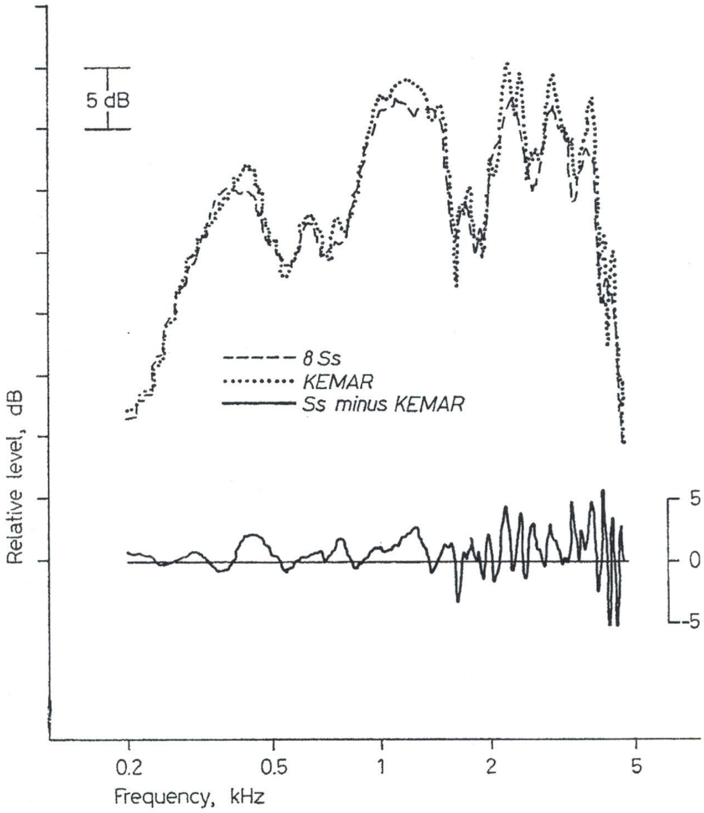

Fig. 3. Output spectrum obtained from a hearing aid with a downward facing microphone in a sound-treated audiometric room and with a signal source azimuth of 0°. The mean spectrum from 8 subjects (---) is compared with the spectrum measured using the Kemar (· · ·). The difference between the two curves is shown below (—).

to the 1.5-cm³ recording coupler. Each earmold serves as a simple adaptor which acoustically seals the outer portion of the KEMAR's ear canal. Each hearing aid is recorded using the length and diameter of tubing with which it is intended to function. This tubing is extended completely through the earmold to its medial tip. Hence, the earmold main bore does not itself exert any influence on the signal.

The Recording Coupler

It was necessary to utilize a recording coupler with a flat transfer function within the frequency range of hearing aids. The size of the coupler was therefore restricted to a range in which no dimension was an appreciable portion of a wavelength of the highest frequency of interest. An upper cutoff frequency of 5 kHz was selected. Most hearing aids currently available do not have an appreciable output above this frequency.

The volume of the recording coupler cavity (1.5 cm^3) was chosen to correspond approximately to the average equivalent volume of the adult ear canal/eardrum enclosed by an earmold. Within fairly broad limits (at least 1–2 cm^3), the volume of the cavity into which the hearing aid receiver works has a minimal effect on the frequency response of the hearing aid's output (the frequency of the receiver's primary peak may be very slightly influenced by a large change in volume).

The final recording coupler was machined of brass in cylindrical form with a length of 12.8 mm and a diameter of 12.2 mm: it was threaded to be compatible with a Brüel & Kjaer 1.3-cm (½-inch) condensor microphone and could conveniently be placed inside the KEMAR's head (substituting for the Zwislocki coupler which usually serves as the KEMAR's ear canal/eardrum).

The Playback System

The playback system was intended to have a minimal influence on the spectrum of the signal being processed by it. It was necessary, therefore, for the frequency response of the system to be as flat as possible through the frequency range thought to be of interest in work with hearing aids. A range of 150 Hz through 5 000 Hz was considered adequate. The playback system consisted of an equalizing network, a playback transducer, and a length of damped tubing, coupling the transducer to the subject's earmold. The flattening of the system's response was accomplished in two steps: first the acoustic coupling of the receiver to the test (1.5-cm^3) cavity was manipulated to give a damped frequency response of adequate bandwidth; second, a simple electrical equalizing network was designed to compensate for the remaining irregularities in the response within the frequency range of interest. The playback transducer was an internal type hearing aid receiver (Knowles BP-1712). An internal type transducer was selected because it would have an acoustic source impedance roughly similar to that supplied by most ear level hearing aids and hence (it was hoped) it would interact with the subject's ear canal/eardrum in approximately the same way as actual ear-level hearing aids would have done. In addition, this receiver was able to meet the minimal requirements of frequency response bandwidth (150–5 000 Hz).

Figure 4 shows the receiver-tubing arrangement used to produce the data shown in figure 6. Other arrangements, differing slightly in details of

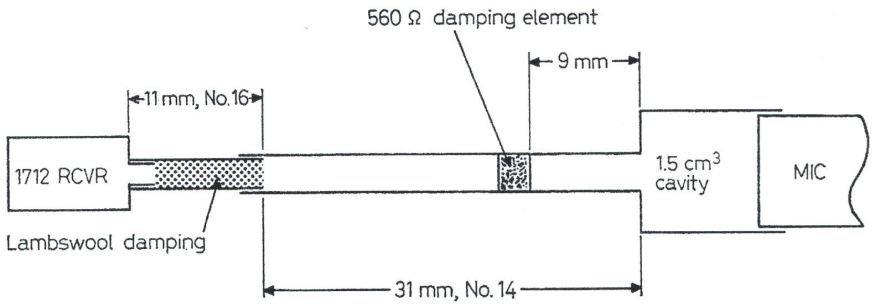

Fig. 4. Schematic drawing of the acoustically damped tubing system coupling the playback transducer to the subject's ear canal.

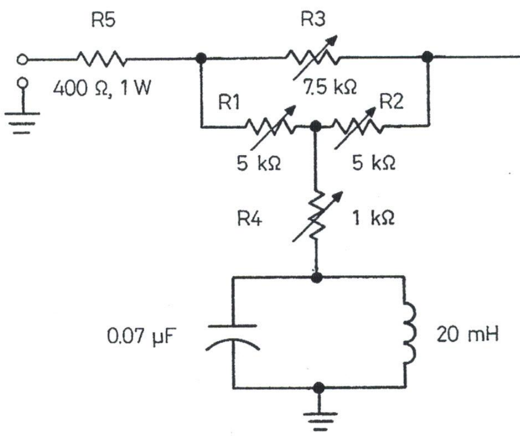

Fig. 5. Circuit of equalizing network used as part of the playback system.

tubing lengths and diameters and/or placement of damping elements have been used with equal success. The major restriction on the acoustic coupling system is that the tubing must be long enough to extend completely through the main bore of the subject's earmold to a position in which the end of the tubing is flush with the medial tip of the earmold. Since the procedure requires the tubing of the playback system to be fully inserted through the main bore of the subject's earmold, it is obvious that this procedure is not suitable for use with side-branch vented earmolds (i.e., earmolds with a vent intersecting the main bore). This is not considered a serious drawback since a previous investigation has shown that side-branch vents result in acoustic changes which are almost never desired in hearing aid use [*Studebaker and Cox,* 1977].

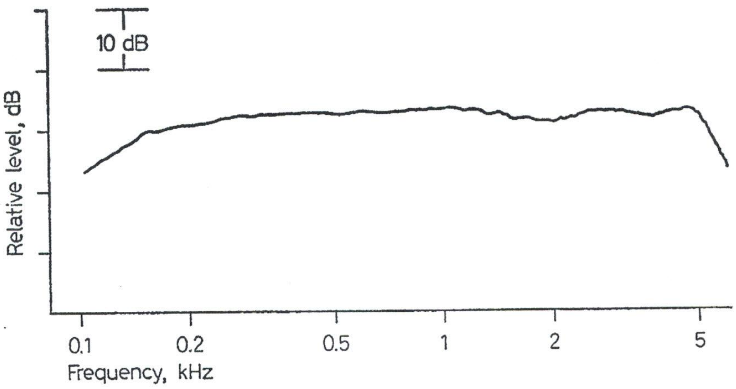

Fig. 6. Frequency response of the playback system used to collect the data shown in figures 7–11. The curve is flat ±1 dB from 150 Hz through 5.0 kHz.

Figure 5 shows the general design of the equalizing network. Basically, this network provides a boost in the 4 500 Hz region. The amount and slope of the boost is adjustable within limits through manipulation of the variable resistors.

Figure 6 shows the response of the final playback system into a 1.5-cm^3 test cavity with the system driven electrically by a flat-spectrum broad-band noise. The response is flat ±1 dB from 150 Hz through 5 000 Hz.

Evaluation of the Procedure

The procedure described in the previous section was evaluated using several categories of ear-level hearing aids and fittings utilizing standard, vented and open earmolds.

In each evaluation, two spectra were obtained and compared. First, a hearing aid was fitted on the KEMAR with a Zwislocki coupler functioning as the KEMAR's ear canal/eardrum; broad-band noise was presented via a 30.5-cm (12-inch) coaxial loudspeaker mounted in a rectangular ducted-port cabinet with a volume of 39.6 dm^3 (1.4 ft^3). The overall level at the location of a front-facing microphone in a hearing aid on the KEMAR's ear was 72 dB. The signal impinging on the Zwislocki coupler microphone was amplified and spectrally analyzed using a Nicolet 440 Real Time Analyzer (RTA), and a hard copy readout of the spectrum was obtained. Second, the recording coupler was substituted for the Zwislocki coupler in the KEMAR (note the acoustic environment was identical for the measurement of the two spectra); the broad-band noise was again presented via the loudspeaker; the signal at the recording coupler microphone was recorded on high-quality magnetic tape using a Revox A77 tape recorder; the tape-recorded signal was amplified and delivered to the playback system; the playback system fed the signal to the Zwislocki coupler which was now mounted alone on a stand. Again, the signal impinging on the Zwislocki coupler microphone (the analog of the subject's eardrum) was spectrally analyzed using the RTA, and a hard copy readout of the spectrum was obtained.

The two spectra thus obtained were compared, the similarity between them being a measure of the extent to which the signal delivered to the eardrum in the 'record/playback' condition was representative of the signal delivered to the eardrum in the directly-aided condition.

An alternative method of evaluating the procedure was used from time to time. This method also involved the comparison of two spectra but these spectra were obtained while driving the hearing aid receiver directly with an electrical signal. The advantage of this method is that it bypasses the effects of the acoustic environment and head diffraction/head baffle, thus eliminating a major source of potential variability. A further advantage of using only the hearing aid receiver rather than the complete hearing aid is the broad frequency response thus obtained – extending to a much lower frequency than most hearing aids are designed to do. The resultant data, free of the effects of environmental acoustics and encompassing the entire frequency range of interest, provide an estimate of the best achievable agreement between the directly-aided and hearing-aid-processed conditions.

Standard Earmold Coupling

Figure 7 shows an example of data obtained using the latter evaluation method. The solid line represents the directly-aided condition and was obtained in a Zwislocki coupler while driving an internal type hearing aid receiver (actually removed from an ear-level hearing aid) with a broad-band flat-spectrum electrical signal. The dotted line represents the record/playback condition and was obtained with the output of the electrically driven hearing aid receiver directed into the recording coupler, the tape recorder, the playback system and finally to the same Zwislocki coupler. In figures 7–11 the vertical placement of the directly-aided and record/playback spectra with respect to each other was adjusted when necessary to give the best agreement between the two curves.

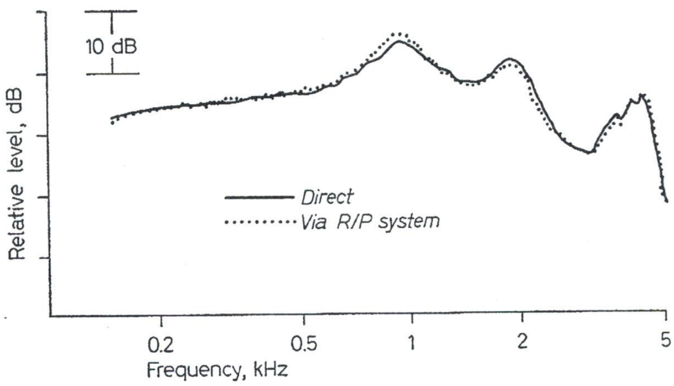

Fig. 7. Spectra obtained in the directly-aided condition (—) and via the record/playback system (· · ·) using an electrically driven hearing aid receiver (instead of the complete hearing aid) and a standard earmold coupling.

It is worth noting at this point that the ultimate presentation level of the record/playback signal is controlled by amplifiers in the playback instrumentation. It could, in theory, be varied throughout the entire range of the playback system. In practice, however, this level should be varied only within the range in which the spectrum of the hearing aid's output remains constant with changes in the input level. This range must be determined for each recorded hearing aid.

There are two major points to be made about the data shown in figure 7. First, the two curves are within ±*2* dB of each other from 150 through 5 000 Hz. This extent of agreement between directly-aided and record/playback conditions was almost always obtainable when using hearing aids (or hearing aid receivers only) coupled to standard or vented earmolds (open earmold fittings are discussed below). Better agreement was obtained on some occasions. This result is indicative of much better agreement between directly-aided and record/playback conditions than was obtained when the more traditional approach, described by *Cox and Studebaker* [1977], was utilized.

Second, the data shown in figure *7* illustrate quite well the only significant limitation observed in the ability of this procedure to reproduce perfectly the spectrum obtained in the directly-aided condition. The primary peak in the receiver's output, which occurs in this figure at about 950 Hz, has a slightly higher Q in the record/playback condition. This is a very consistent finding and appeared to be the main source of error under all earmold conditions (see below for a discussion of a means to eliminate this error). The origin of the discrepancy is in the different loads presented to the hearing aid receiver/tubing in the directly-aided condition (the Zwislocki coupler) and the recording phase of the record/playback condition (the 1.5-cm^3 cavity). The resultant difference between directly-aided and hearing-aid-processed spectra, however, is usually no greater than +2 dB as shown in figure 7, and differences as large as +3 dB have been seen only on rare occasions.

Figure 8 shows the results of a directly-aided/hearing-aid-processed comparison obtained using an ear-level, high-frequency emphasis, compression hearing aid with a forward facing microphone. The acoustic signal was a white noise presented at an overall level of about 72 dB at the location of a front-facing microphone in a hearing aid on the KEMAR's ear and transduced by the 30.5-cm (12-inch) coaxial loudspeaker described earlier. The signal source azimuth was 0°. The solid line is the spectrum observed at the microphone of the Zwislocki coupler in the directly-aided condition (i.e., the hearing aid on the KEMAR with the Zwislocki coupler functioning as the KEMAR's ear canal/eardrum). The dotted line is the spectrum observed at the microphone of the Zwislocki coupler in the record/playback condition (i.e., the hearing aid on the KEMAR with its output directed to the recording coupler, the tape recorder, the playback system, and finally the Zwislocki coupler).

The point of major interest in figure 8 is the extent of agreement between the spectra obtained in the two conditions. The record/playback data are within ±2dB of the directly-aided data throughout the effective frequency range of the hearing aid. Similar comparisons were made using peak-clipping hearing aids, aids with downward facing microphones and an aid with the gain control and input level increased so that the instrument was in saturation. The results all showed differences between conditions of the same order of magnitude as shown in figure 8. It is of interest to note that close inspection of the data in figure 8 reveals a pattern identical to the one shown more clearly in figure 7 because of the absence of the effects of the acoustic environment: the main discrepancy between the two conditions occurs at about 900 Hz – the probable location of the primary resonance of the receiver-tubing combination.

An important aspect of the data shown in figure 8 is the markedly irregular configuration of the curves. This result is due largely to the acoustic environment in which the data were obtained – a sound-treated audiometric room the surfaces of which, for reasons unrelated to this investigation, were

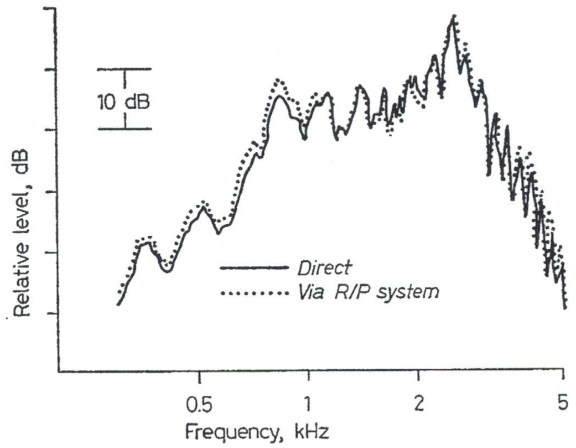

Fig. 8. Spectra obtained in the directly-aided condition (—) and via the record/playback system (· · ·) using a high-frequency emphasis ear-level hearing aid with a standard earmold fitting.

about half covered with tempered masonite reflecting panels. The environment was, therefore, a small, moderately reverberant room. Use of an environment of this type permitted demonstration of the very considerable accuracy with which the record/playback procedure used here reproduces the details of the effects of the acoustic environment: the standing wave pattern is virtually unchanged from the directly-aided condition to the record/playback condition.

Modified Earmold Coupling

The procedure described in this paper for obtaining hearing-aid-processed signals was intentionally designed to incorporate the use of the subject's individually fabricated earmold. This aspect of the procedure was seen as important because of the extent to which the characteristics of the earmold may influence the spectrum presented to the subject's eardrum. It was necessary, therefore, to evaluate the extent to which a given modified (vented or open) earmold would have the same effect on the spectrum of a record/playback signal as it would have had on the spectrum of the directly-aided signal.

Earmolds incorporating parallel vents were evaluated using electrically driven hearing aid receivers rather than complete hearing aids. The receivers alone offered the advantage of good low-frequency response with a standard

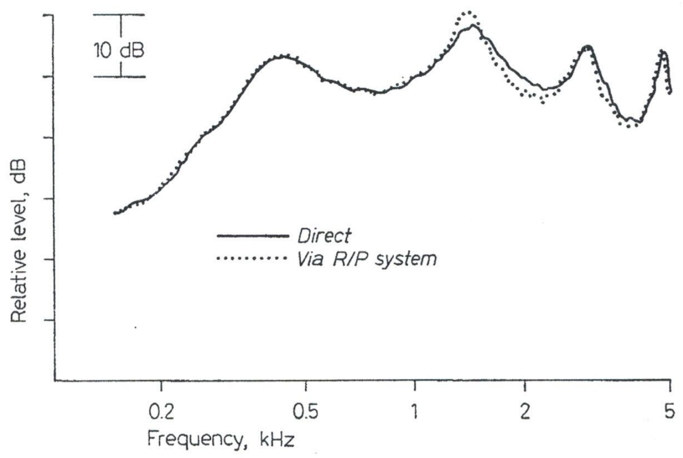

Fig. 9. Spectra obtained in the directly-aided condition (—) and via the record/playback system (dotted line) using an electrically driven hearing aid receiver (instead of the complete hearing aid) and a parallel-vented earmold coupling.

earmold coupling. Hence, the low-frequency filtering effect of an earmold vent was easily observable in the data.

Vents of various diameters were evaluated; all with basically the same results. Figure 9 shows a typical example of the extent of the agreement between the directly-aided spectrum (solid line) and the record/playback spectrum (dotted line) obtained with an earmold incorporating a parallel vent. The record/playback data curve is within ± 2 dB of the directly-aided curve from 150 Hz through 5 kHz. The primary peak in the receiver's output is again the area of maximum discrepancy between the two curves. The reactance resonance associated with the vent is observable at about 430 Hz, below this frequency the low-frequency filtering effect associated with vents is clearly seen. The two data curves are virtually identical throughout the frequency region in which the vent has an effect on the spectrum. These data indicate that a vented earmold could be incorporated into a procedure using hearing-aid-processed signals obtained as described here with the expectation that the acoustic effect of the vent would be equivalent to its effect when coupled to the hearing aid in a directly-aided condition. The same reasoning applies to the effects of leaking or poorly sealed 'unvented' earmolds.

It is worth noting at this juncture that although the use of record/playback signals with vented earmolds results in the appropriate spectrum-shaping associated with the vent, it is not subject to the effects of one of the

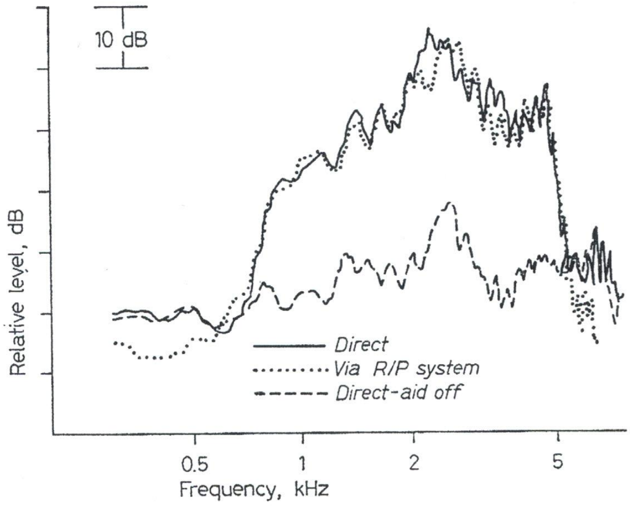

Fig. 10. Spectra obtained in the directly-aided condition (—) and via the record/playback system (· · ·) using an ear-level hearing aid with an open earmold fitting. --- = Spectrum of the signal at the Zwislocki coupler microphone with the hearing aid turned off (i.e., the directly-received signal).

well-known disadvantages of earmold leaks in general, namely, acoustic feedback. Since the microphone of the hearing aid is not physically present when the record/playback signal is used, the loop necessary to establish acoustic feedback is not complete and feedback will not occur regardless of the amount of gain delivered to the ear canal. Clearly, this could result in an inappropriate gain setting. A mechanism to determine the maximum usable gain for a given earmold must be developed to deal with this problem.

The utilization of open earmolds in the hearing-aid selection procedure incorporating prerecorded hearing-aid-processed signals was also evaluated. The stated objectives in the employment of an open earmold are often two-fold: (1) to provide high-frequency amplification without low-frequency amplification, and (2) to provide direct access to the ear canal for unamplified sounds, presumably to allow 'normal' reception of low frequencies. The data indicate that the results of the first objective can be adequately simulated using a hearing-aid-processed signal. However, the second objective is not achieved, as data presented below demonstrate.

The solid line in figure 10 shows the spectrum obtained in the directly-aided condition for an ear-level hearing aid, with a downward facing microphone, fitted to the KEMAR's ear using an open earmold. The input signal was again a white noise presented via the previously described loudspeaker at a level of about 72 dB SPL at the location of a front-facing microphone in a hearing aid on the KEMAR's ear. The dotted line shows the spectrum obtained in the record/playback condition. The dashed line shows the spectrum measured at the KEMAR's 'eardrum' with all the conditions the same as for obtaining the solid line but with the hearing aid turned off. The dashed line, therefore, shows the spectrum and relative level of the unamplified signal reaching the 'eardrum'. The figure shows quite clearly that the record/playback spectrum (the dotted line) corresponds only to the amplified portion of the total signal reaching the Zwislocki coupler microphone.

From about 600 through 5 000 Hz the spectra obtained in the directly-aided and the record/playback conditions are very similar with only a few narrow frequency regions exceeding the maximum difference of ± 2 dB typically found with standard and vented earmold fittings. In the frequency region between 300 and 560 Hz the spectrum level of the record/playback signal is as much as 7 dB lower than that of the directly-aided signal. It would appear from these data that the directly received signal, represented by the dashed line, determines the level of the spectrum at the eardrum at frequencies below a cut-off frequency determined by the open mold and the particular ear involved (in the case of this open earmold and the KEMAR's ear the cut-off frequency was in the vicinity of 600 Hz). From this frequency to the upper cut-off frequency of the hearing aid the spectrum level of the directly-aided curve is determined primarily by the amplified component of the signal. Above the upper cut-off frequency of the hearing aid, which in figure 10 occurs at 4 700 Hz, the directly received signal is again the main component of the spectrum observed in the directly-aided condition; the peak in the curve at about 6 200–6 400 Hz seems almost entirely attributable to the directly received signal.

The results shown in figure 10 are very similar to those obtained in one of the two other hearing aids tested using an open earmold fitting (the third hearing aid is shown in figure 11). It seems clear, both intuitively and experimentally, that the directly received component of the signal normally available in a hearing aid fitting utilizing an open mold will not be present in the analogous record/playback signal presented via an open earmold. Whether or not this discrepancy between directly-aided and hearing-aid-processed signals is of practical significance is a matter for investigation.

Figure 11 shows another example of a directly-aided (solid line) spectrum compared to a record/playback (dotted line) spectrum obtained using

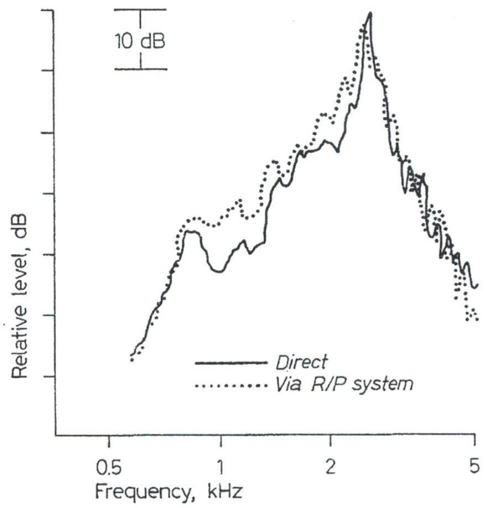

Fig. 11. Spectra obtained in the directly-aided condition (—) and via record/playback system (· · ·) using an ear-level hearing aid with an open ear-mold fitting. These data show the greatest discrepancies between directly-aided and hearing-aid-processed spectra observed under any circumstances.

an ear-level hearing aid fitted to the KEMAR with an open earmold. These data are presented because they show the poorest agreement observed between directly-aided and hearing-aid-processed spectra using any hearing aid or any type of earmold. Differences as large as 5 dB were observed between the two curves across a fairly broad frequency range. The maximum difference was 7 dB at 1–2 kHz. It is difficult to speculate about the possible causes of the discrepancies observed between these curves because the areas in which discrepancies seem to occur depend on the vertical placement of the two curves with respect to each other. In figures 7 to 10 the appropriate vertical placement of the two data curves with respect to each other seemed rather obvious. In figure 11, it was less so. As the data are shown here, it appears that the level of the directly-aided signal is lower than that of the record/playback signal across a frequency range extending from about 800 Hz to 2.5 kHz. *Berland* [1975] reported a phenomenon which might be relevant to this observation. He noted that because of the presence in the ear canal of a signal comprised of a directly-received component in combination with an amplified component of the same original stimulus, cancellation effects due to phase differences could occur. Such an effect might explain the data shown in figure 11 in which the level of the signal in the condition consisting of combined amplified and direct sound is less, in some frequency regions, than the level of the signal in the condition consisting of amplified sound only. This effect, if verified, would be an unpredictable source of error in any procedure utilizing hearing-aid-processed signals in combination with an open mold fitting.

Comments

An Alternative Approach

It was noted earlier that there is a small but consistent error in the production of record/playback signals using the procedure described in this paper, namely, an increase in the Q of the primary resonance of the hearing aid receiver due to the difference in damping load provided by the Zwislocki coupler in the directly-aided condition and the 1.5-cm^3 recording coupler in the record/playback condition. Preliminary investigations indicated that this error could be eliminated by using a Zwislocki coupler as the recording coupler if a weighting network was incorporated into the system which removed the spectrum-shaping effects of the Zwislocki coupler from the recorded signal. This procedure eliminates the change in the Q of the hearing aid receiver's primary resonance by providing the same load in the record and playback situations. The outcome is a reduction in the directly-aided-record/playback discrepancy from ± 2 to ± 1 dB. The ± 1 dB appears to be irreducible and is the result of the lack of a perfectly flat playback system and possibly the combined effects of other uncontrolled factors.

Effects of Individual Variability

The data presented in figures 7–11 illustrate the extent to which the procedure for obtaining record/playback signals which is described herein may be expected to result in a signal spectrum at the subject's eardrum which is the same as the spectrum the subject would have received if the hearing aid itself had been placed on his ear. These data indicate that when ear level hearing aids are fitted to the KEMAR using standard or parallel-vented earmolds and a Zwislocki coupler is used as the KEMAR's ear canal/eardrum, the discrepancy between directly-aided and record/playback spectra is typically ± 2 dB. When the hearing aid is fitted using an open earmold, the record/playback spectrum is usually within ± 2 dB of the amplified component of the directly-aided spectrum (there may be narrow frequency regions in which the difference is somewhat larger), but the directly-received component of the directly-aided spectrum is absent.

In addition to the typical difference of ±2 dB shown in these data, differences due to variability in head diffraction/baffle effects across real heads and in impedance values across real ears may be expected to contribute further to discrepancies between directly-aided and record/playback spectra.

The variability across subjects in head diffraction/baffle effects for a signal at 0° azimuth in a sound-treated audiometric room cannot be stated with any certainty at this time. Preliminary data indicate that the standard deviation of these effects for a group of 8 subjects is <1 dB at 400 Hz and <4.5 dB at 4 000 Hz. The actual variability may be considerably less than these figures.

The effect on ear canal sound levels of variability in ear canal/eardrum impedance values across subjects is another issue on which there are little available data. An estimate may be derived from data published by *Sachs and Burkhard* [1972]. These data indicate that the standard deviation of the effect is <1.5 dB at 400 Hz and <3.5 dB at 4 000 Hz.

The separate variabilities associated with head diffraction/baffle effects and ear canal/eardrum impedance effects will combine with each other in a manner which is not readily predictable. Further investigation is necessary before the effect of individual variability on the similarity of hearing-aid-processed signals to directly-aided signals can be estimated with any confidence.

It has been the experience of these authors that the most crucial factor in the success of this procedure for obtaining and utilizing record/playback signals is the adjustment of the playback system to provide as flat a frequency response as possible. This adjustment with the described system was quite difficult to achieve, but once achieved, it remained fairly stable. However, provision should be made for checking the frequency response of the playback system on a regular basis.

Résumé

L'utilisation des signaux de paroles enregistrés après passage à travers un appareil de correction auditive est une méthode commode, mais qui introduit des changements dans la pression acoustique et dans le spectre. Aussi, utilisant le mannequin KEMAR, nous avons imaginé un nouveau moyen d'enregistrement permettant d'augmenter la confiance dans cette méthode, quels que soient les embouts utilisés: standards, perforés ou ouverts.

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