Objective Measure of Low-Frequency Amplification Reduction in Canal Hearing Aids with Adaptive Circuitry

Stephen W. Painton*

Abstract
The total amount of "ampclusion" (low-frequency amplification + occlusion) and its reduction were measured in two identically fitting canal hearing aids with three circuitry capabilities: (1) K-Amp, (2) linear, and (3) noise reduction (ANP II). The insertion gains of all three circuits were adjusted to be closely matched and the amounts of occlusion for both aids were almost identical. Real-ear measurements were obtained as the author vocalized the phoneme /i/ at 65 dB SPL at 2 ft in three conditions: (1) unoccluded, (2) occluded, aid off, and (3) occluded, aid on. The results indicated a reduction in the low-frequency amplification component of ampclusion for both adaptive circuits when compared to the linear circuit, with the K-Amp showing slightly greater reduction than the ANP II. These findings suggest that in addition to noise-reduction circuitry, K-Amp circuitry will also provide a more pleasant experience to the hearing aid wearer when listening to his/her own voice.

Key Words: Ampclusion, K-Amp, noise reduction, occlusion effect

In 1990, almost 20 percent of all ITE hearing instruments fit were canal hearing aids (Hearing Industries Assn., 1990). Despite the increased popularity of the canal aid, however, audiologists still encounter the wearer of canal aids presenting complaints of "hollowness," "voice in my nose," or simply "too loud" with respect to his/her own voice. In fact, at least two investigators have reported that displeasure with the perception of their own voices was the primary reason for many wearers' rejection of canal hearing aids (Johnson, 1985; Dempsey, 1990). The occlusion effect has been singled out by most investigators as being responsible for such complaints (Wimmer, 1986; Westerman, 1987; Dempsey, 1990). This phenomenon, originally described by Wheatstone in 1827 (cited in Dirks, 1973), is an improvement in low-frequency, bone-conduction thresholds when the ear canal is obstructed. Relating more specifically to amplification, occlusion often occurs in ITE/ITC instruments with little or no venting and results in the hearing aid wearer hearing the low-frequency, voiced energy of his/her own voice louder than usual via bone conduction. In addition to simple occlusion, however, when the instrument's frequency response is such that it provides gain at frequencies below 1000 Hz, additional low-frequency energy from the air-conducted component of the wearer's voice will be routed into the auditory canal when he or she speaks. In fact, it has been reported that the intensity of the wearer's own voice at the hearing aid microphone could be as great as 15 dB more intense than the voices of other speakers (Dunn and Farnsworth, 1939). There is evidence to suggest that it is the phenomenon of "ampclusion," the combination of occlusion and low-frequency amplification, that results in the "hollowness" or "head in a barrel" complaints. In fact, several authors, while suggesting deeply sealed earmolds as a solution for this effect, have alluded to the fact that a wearer's own amplified voice, added to the occluded voice will result in the "hollowness" problem (Killion et al, 1988; Bryant et al, 1991; Staab and Finlay, 1991). Empirically, this contention is borne out by the practice of successfully remediating the
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“hollowness” problem by addressing either occlusion alone (deeply sealed earmolds and open earmolds), low-frequency amplification alone (tone controls and volume controls), or a combination of both (enlarged vents and shorter canals). Regardless of the approach used, the end result sought is the reduction of low-frequency energy in the canal of the wearer resulting from his or her own voice. Recently, Kuk (1990) and Kuk et al. (1992) have published studies showing that “hollowness” of the wearer’s voice can be diminished by decreasing the low-frequency amplification and perhaps to some extent, the overall gain in hearing aids. The earlier study showed that hearing-impaired subjects preferred a different amount of insertion gain in their hearing aids when listening to a speaker than when reading aloud. Specifically, the subjects with hearing loss in both the low- and high-frequency regions tended to prefer less gain (both low-frequency and overall) when listening to themselves read aloud than when listening to others speak. Kuk’s explanation was that these persons were being subjected to both the occlusion effect and increased SPL in their canals caused by amplification when they spoke into their hearing aids. Kuk’s conclusion was that the most reasonable approach to this “hollowness” problem would be to fit individuals with multimemory programmable hearing aids. Such a hearing aid would be programmed to operate with one frequency response for listening and another frequency response for speaking.

The latter study by Kuk et al. (1992) examined the ability of noise-reduction hearing aids to reduce the “hollowness” of one’s own voice by automatically decreasing the low-frequency gain and to some degree, overall gain when the wearer speaks. Kuk’s contention was that, because the perception of “hollowness” depends primarily on the low-frequency gain and to some extent the overall gain of the hearing aid, a reduction in both factors will result in an improvement in the perceived quality of one’s own voice. The results of the study showed that noise-reduction hearing aids can indeed improve the self-perceived quality of the wearer’s own voice. The reduction of “hollowness” was particularly evident with subjects who had hearing loss in the low frequencies, requiring low-frequency amplification. These subjects perceived a decrease in “hollowness” as this particular type of adaptive circuitry reduced the amount of low-frequency gain.

The latest addition to the family of adaptive circuitry is the K-Amp circuit (Killion Amplifier). While the K-Amp is technically a single-channel compressor, it has a level-dependent frequency response that results in maximum gain across the frequencies with low input and minimum gain with high input (Preves, 1992). In other words, it acts as a sensor that reacts to the most intense sound in the environment, which, among other things, assures that the wearer will never be subjected to overly amplified sounds. Revisiting the problem of “ampsclusion,” it appears that the K-Amp circuit should respond even more favorably than a typical noise-reduction hearing aid in decreasing both the low-frequency and overall amplification of one’s own voice because of its continuous adaptation to the environment. Specifically, if the K-Amp circuitry responds by decreasing the low-frequency amplification component of “ampsclusion,” then the result should be less “hollowness” and a more natural sounding voice of the wearer.

The present study examined objectively the decrease in low-frequency gain and overall gain (up to 1000 Hz) experienced with both a K-Amp and noise-reduction canal hearing aid during wearer vocalization. Specifically, we sought to measure and compare amounts of “ampsclusion” with three types of circuits in canal hearing aids (K-Amp, ANP II, and linear) while controlling for insertion gain, vocalization intensity, and occlusion.

METHOD

Hearing Aids

Two canal hearing aids, which were constructed by Finetone Hearing Instruments, Inc. for the author’s left ear, were used. The two aids, which had two distinctively different circuits, were a Finetone K-Amp (aid #1) and a Finetone ANP II (aid #2). The K-Amp is an adaptive circuit that is constantly increasing or decreasing its gain in response to the intensity of the input stimulus. This particular aid was adjusted for maximal gain (TK control) and maximum low-frequency emphasis (LFC control) and featured Finetone’s relatively flat “fixed frequency response” and waxguard. The ANP II is a noise-reduction hearing aid with separate trimmer pots for low-frequency reduction and overall compression. Put simply, the ANP II hearing aid, when adjusted accordingly, will react to intense, broadband stimuli as would most so-called “noise-reduction” aids. That is, it would reduce primarily the amount of low-
frequency gain and to some degree the overall gain. In addition, the aid was constructed by Finetone so that when the trimmers were adjusted fully clockwise, it became a hearing aid with a linear circuit (i.e., no low-frequency gain reduction or compression). Varying amounts of compression and low-frequency reduction, however, were available as the trimmers were rotated counterclockwise, so that in this study the same hearing aid was able to be used as two distinctively different circuits, totalling three different circuits for the study. Both hearing aids were the same style/size (canal) and length (2 cm) and had real-ear probe tubes extending 4 mm from their sealed, nonfunctional vents.

Test Equipment and Stimuli

A Fonix 6500 probe mic system was used to obtain the insertion gain, occlusion, and ampclusion data from the three hearing aid circuits. This computerized system consists of both a stationary and remote control panel, a height-adjustable, portable loudspeaker, a viewing screen, a reference microphone, and a probe microphone attached to a soft, flexible silicone probe tube. A speech-weighted composite noise presented at 55 dB SPL was the stimulus used when obtaining all insertion gain recordings. This relatively low-intensity stimulus was used to enable the K-Amp circuit to achieve significant gain. The occlusion and ampclusion recordings were obtained with the author vocalizing the phoneme /i/ at 65 dB SPL as measured at 2 feet. The phoneme /i/ was chosen because of its low first formant and its ability to show occlusion (Killion et al, 1988). The intensity of 65 dB SPL was chosen because it closely approximates the soft-to-normal speech levels used by Kuk et al (1992). A precision sound level meter (Quest 155) was used to monitor the intensity of the vocalized /i/ during the simple occlusion and ampclusion recordings. All recording was done in an anechoic chamber during one 2-hour session.

Procedure

The session began with the probe mic system set up to obtain the insertion gain measures of both hearing aids with 55 dB SPL input. The probe tube was measured and marked to assure that it was placed in the canal at a depth of 4 mm beyond the opening of the aids' sound channels. After the unaided response was recorded, the probe tube was removed, aid #1 (K-Amp) was inserted, and the probe tube, which protruded from the vent of the aid, was connected to the microphone assembly. The aided response/insertion gain was then obtained and saved with the volume control set to just below feedback. The aid was then carefully removed so as not to alter the volume control setting, the battery compartment of the aid was opened, and the probe tube was disconnected from the microphone assembly. Aid #2 (linear) was then inserted into the canal, and its probe tube was connected to the microphone assembly. (Because the unaided response for this canal had been obtained and saved previously, it was not necessary to repeat that measure.) The aided response/insertion gain of aid #2 was then matched (below 1000 Hz) to the aided response/insertion gain of aid #1 by varying the volume control (Fig. 1). It was then removed with care so as not to alter the volume control setting. As well, the battery door was opened, and the probe tube was disconnected from the microphone assembly. It is important to emphasize that, because the probe tubes protruding from the two aids were positioned in identical places in the canal and the same unaided response was used for both measures, the insertion gain recordings should be considered valid.

The probe mic system was then modified to accommodate the recording of occlusion and ampclusion. Namely, the soundfield speaker was unplugged and the reference microphone was disabled. A probe tube was connected to the microphone assembly and inserted into the canal to a depth of 4 mm beyond the opening of the hearing aids' sound channels. The author then vocalized the phoneme /i/ at the intensity of 65 dB SPL. This curve was recorded and saved. After removing the probe tube from the canal, aid #1 was inserted into the canal with the battery door still open so as not to have any
amplification present and its probe tube was connected to the microphone assembly. The phoneme /i/ was then vocalized at 65 dB SPL, and the recording attributed to the occlusion of aid #1 was saved. The battery door on aid #1 was then closed, allowing for normal operation of the hearing aid at the set level of amplification. The phoneme /i/ was then vocalized again and the recording of occlusion for aid #1 was saved. The same protocol was used for the aid with the linear and noise-reduction circuitry when obtaining the respective occlusion and amplclusion recordings. A comparison of the occlusion curves for the two aids is shown in Figure 2. Adjustment of the two trimmers when changing from the linear circuit to the noise-reduction circuit was done so that the insertion gain curve at 55 dB SPL input was not altered.

RESULTS

The amplclusion curves attributed to each of the three circuits, along with a composite occlusion curve, are shown in Figure 3. The differences in amplclusion between the linear circuitry and the two adaptive circuits are apparent. The linear circuit amplclusion curve is parallel to the amplclusion curves of the two adaptive circuits, but is between 6 to 19 dB more intense at all frequencies. The K-Amp circuit provided the most reduction in amplification up to approximately 800 Hz, at which point the amplclusion curve for the ANP II intersected the amplclusion curve for the K-Amp. The two curves then crossed once more just below 1000 Hz. A composite occlusion curve was included in Figure 3 to show (1) the magnitude of decrease in the low-frequency amplification component of both adaptive circuits in contrast to the linear circuit, (2) how close the adaptive circuits' amplclusion curves were to the occlusion curve, and (3) a better perspective on why linear canal aids with low-frequency amplification can result in the wearer perceiving a “hollowness” in his/her own voice.

DISCUSSION

The present study shows that both the K-Amp and ANP II circuits are effective in reducing the low-frequency amplification component often associated with wearer voice “hollowness” in comparison to a linear circuit with matching insertion gain values. This is an important finding since the perception of “hollowness” is a major reason for patient dissatisfaction with their hearing aids (Johnson, 1985; Zelnick, 1987; Dempsey, 1990). Even though the present study was performed with canal hearing aids, the results should be valid to some degree for all in-the-ear instruments.

The results of this study offer objective evidence to support the hypothesis of Kuk et al (1992) regarding the capability of noise-reduction hearing aids to improve the self-perceived quality of the wearer’s own voice. In addition, the results offer objective evidence suggesting that the K-Amp circuit may be at least as effective as noise-reduction circuitry in reducing “hollowness” in the wearer’s voice. This new evidence is timely because of the recent introduction of the K-Amp circuitry by many hearing aid manufacturers and the concomitant evolution of appropriate fitting strategies for that particular circuitry. Specifically, there are several implications to these findings regarding K-Amp circuitry fittings. Due to the automatic reduction of low-frequency gain when the wearer speaks, the fitting professional will not need to be as concerned with some of the past consequences of low-frequency amplification (e.g., hollowness, loudness, or self-masking). In addi-
tion, vent size should be able to be reduced in hearing aids in which the K-Amp circuitry is providing some low-frequency amplification without the fear of increasing the "hollowness" effect. This is an especially important consideration because of the K-Amp circuit's propensity for acoustic feedback in quiet listening environments (Preves, 1992). Further, the K-Amp circuit may offer a partial solution to the dilemma professionals sometimes encounter when potential hearing aid wearers with hearing loss only in the high frequencies prefer some low-frequency amplification for sound quality (Punch and Beck, 1980). In fact, the comparatively flat "fixed-frequency" response of the K-Amp circuit used in this study could conceivably be considered an appropriate alternative for such cases.

In summary, this study has shown that both the K-Amp circuit and the ANP II noise-reduction circuit may be able to reduce the self-perceived "hollowness" in the voices of canal hearing aid wearers by automatically decreasing the amount of low-frequency gain when he or she speaks. In essence, these circuits are able to perform as suggested was necessary by Kuk (1990), that is, one frequency response for listening and another for speaking. A suggestion for further research would be a psychoacoustic study in which the elusive "hollowness" could be recorded, digitized, studied, and broken down into its components.

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REFERENCES


