A Comparison of Single-Channel Linear Amplification and Two-Channel Wide-Dynamic-Range-Compression Amplification by Means of an Independent-Group Design

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The present study used an independent-group design to compare the benefits provided by binaural, single-channel, linear, full-shell in-the-ear hearing aids and binaural, 2-channel, wide-dynamic-range-compression in-the-canal hearing aids in groups of older hearing aid wearers. Hearing aid outcome measures were obtained at both 1-month (n = 53) and 6-month (n = 34) postfit intervals with each device. Outcome measures included multiple measures of speech-recognition performance and self-report measures of hearing aid benefit, satisfaction, and usage. Aided sound-quality measurements were also obtained. Although both devices provided significant benefits to the wearers, there were no significant differences in the benefits provided by either device at the 1-month or 6-month postfit intervals.

Key Words: hearing aids, compression, elderly

Over the past few decades, there has been much interest in the systematic comparison of the benefits provided by differing hearing aid technologies. This has involved a comparison of static versus adaptive frequency responses (e.g., Humes, Christensen, Bess, & Hedley-Williams, 1997), single-band linear versus single-band compression instruments (e.g., Larson et al., 2000), or multiple-channel compression versus single-channel compression devices (e.g., Moore & Glasberg, 1986). Single-channel linear devices have been compared frequently with two-channel wide-dynamic-range-compression (WDRC) hearing aids, with somewhat mixed results obtained regarding advantages of one technology over the other (Humes et al., 1999; Moore, Johnson, Clark, & Pluviance, 1992; Newman & Sandridge, 1998; Walden, Surr, Cord, Edwards, & Olson, 2000).

Most comparisons of single-channel linear and two-channel WDRC technologies have used either within-subject designs or between-subjects designs that have not systematically matched the experimental groups for potentially confounding variables. In studies using within-subject designs, also referred to as repeated measures or crossover designs, the same participants typically experience all devices or technologies involved in the study, coupled with wearing periods of 4 to 12 weeks for each technology. In many of the studies making use of such a research design, the group of hearing aid wearers is divided into subgroups, and counterbalancing is used to negate the effects of order. It is not always the case, however, that the subgroups of participants in a particular within-subjects study have been equated for prior hearing aid use. Prior hearing aid use can have a significant influence on subsequent outcome measures (e.g., Humes, 2003). By the time the first 4–12-week trial period has been completed for any inexperienced hearing aid wearer, that wearer can no longer be considered inexperienced. Thus, even when counterbalancing the order in which the technologies have been evaluated has been used in within-subject designs comparing technologies, order effects will be minimized only when the subgroups receiving each possible order have been matched for prior hearing aid experience. Specifically, all participants must be experienced hearing aid wearers with the amount of prior experience far exceeding the combined durations of the trial periods in the within-subjects design. The likelihood of this potentially confounding factor affecting the results most likely increases as the trial period for the use of each technology increases. Yet, there is some evidence (e.g., Yund &
Buckles, 1995a) that trial periods of several months may be needed to optimize the benefits received from at least some forms of compression amplification.

To better illustrate the potentially confounding influences of an extended trial period on crossover designs, consider the following scenario. A group of 200 participants was randomly divided into two subgroups of 100 participants each. Subgroup 1 had 80 new hearing aid wearers with the rest (20) being experienced users. Subgroup 2, on the other hand, had 20 new hearing aid users and 80 experienced wearers. Subgroup 1 received Technology A followed by Technology B, whereas the order was reversed for Subgroup 2. When all 200 participants completed both portions of the study, 180 of the 200 participants were experienced hearing aid wearers by the time they tried Technology B, whereas only 120 of the 200 participants were experienced hearing aid wearers when they tried Technology A. If prior hearing aid experience mattered for the particular outcome measures used to evaluate the technology under investigation, then the comparison would be biased either in favor of or against Technology B, depending on the nature of the association between prior experience and the outcome measures used.

There are several reasons that crossover designs have been used in many comparisons of hearing aid technologies, including comparisons of single-channel linear and two-channel WDRC devices. Compared with the primary alternative design, an independent-group or between-subjects design, within-subject designs eliminate the need to match groups of participants for potentially confounding variables and also reduce the total number of participants that must be enrolled in the study. Depending on the technology comparison involved, moreover, the costs incurred to supply all participants with study hearing aids can be considerably greater in independent-group designs. In the previous repeated measures design example, 200 hearing aids (assuming monaural fits) would be required to compare Technology A and Technology B if the change in technology could be accommodated by a switch on the device or reprogramming of the instruments. For the same number of participants receiving both technologies in an independent-group design, however, 400 hearing aids would be required. Basically, for the comparison of X technologies, the cost of the devices alone increases X times for a between-subjects investigation compared with a within-subject study. This is the cost of the devices alone. There are also additional costs of time for the independent-group design, especially time devoted to the recruitment, screening, enrollment, and oversight of study participants.

Although there are valid reasons for choosing crossover designs for comparative evaluation of hearing aid technologies, as noted previously, there can be biases introduced into such designs, even when counterbalancing the order in which the technologies are evaluated across participants. Such order effects are eliminated in independent-group designs since each group experiences only one technology. The key to unbiased comparisons in this type of design is that the groups must be equivalent with regard to potentially confounding extraneous variables. Equivalence is achieved typically through random assignment for large groups or some form of matching for smaller groups of participants. Given the smaller study samples used in most hearing aid studies, matching of participants is preferred over random assignment.

In this study, we wished to compare the benefits provided by binaural, linear, full-shell, in-the-ear (ITE) hearing aids with those provided by binaural, two-channel, WDRC in-the-canal (ITC) devices over an extended 6-month period of hearing aid use by older hearing aid wearers. The basic question addressed was whether the differences in hearing aid circuitry and style resulted in measurable differences in hearing aid outcome, even after a prolonged period of hearing aid usage. The opportunity for such a comparison grew out of our recent work on the modeling of hearing aid outcome measures (Humes, 2003). For that work, the focus was on identification of the relevant dimensions of hearing aid outcome, beginning with a large group (n = 173) of older adults fitted with single-channel, linear, ITE hearing aids. To determine whether the outcome dimensions identified for that style and technology of hearing aid could be generalized to other hearing aid circuits and styles, a smaller group (n = 53) of older adults fitted with two-channel, WDRC ITC devices was evaluated. The availability of a large and identical set of outcome measures from both groups afforded us the opportunity to compare the performance of each technology across groups while matching for potentially confounding variables that could affect such a comparison. Whereas differences in circuitry (single-channel linear versus two-channel WDRC) might have an impact on all outcome measures used in this study, the differences in style (full-shell ITE vs. ITC) would most likely affect only the self-reported satisfaction and usage measures (Hosford-Dunn & Halpern, 2001).

The two groups of 53 participants in this study, each receiving one of the two devices, were matched in terms of age, gender, hearing loss, and prior hearing aid experience. Although the potentially confounding effects of group differences in participant age, hearing loss, or prior hearing aid experience on a large set of outcome measures are obvious, this is probably less so with regard to group differences in gender. However, in unreported predictive modeling of hearing aid outcome measures, along the lines described recently by Humes (2003), gender differences had occasionally been observed in self-reported outcome measures and in the underlying variables that affect such measures. As a result, gender was also included as a matching variable in this study. Additional procedural details are provided in the following section.

Method

Participants

The participants in this study were recruited for one of two longitudinal studies on hearing aid outcome measures via newspaper ads, flyers posted in the community, printed announcements in church/synagogue bulletins, and word of mouth. All participants enrolled in the study met the following selection criteria: (a) age between 60 and 89 years; (b) hearing loss that was flat or gently sloping (from
250 to 4000 Hz; no interoctave change in hearing thresholds of more than 20 dB); (c) hearing loss that was of sensorineural origin (normal tympanometry and air–bone gaps no greater than 10 dB at three or more frequencies); (d) hearing loss that was bilaterally symmetrical (interaural difference within 30 dB at all octave and half-octave intervals from 250 to 4000 Hz); (e) pure-tone thresholds within the following ranges: 5–85 dB HL (American National Standards Institute, 1996) at 250 Hz, 5–85 dB HL at 500 Hz, 10–90 dB HL at 1000 Hz, 20–95 dB HL at 1500 Hz, 25–95 dB HL at 2000 Hz, 30–120 dB HL at 3000 Hz, 30–120 dB HL at 4000 Hz, and 30–120 dB HL at 6000 Hz; (f) no known medical or surgically treatable ear-related condition; (g) no known fluctuating or rapidly progressing hearing loss; (h) no cognitive, medical, or language-based conditions that may have limited the participant’s ability to complete the procedures used in the longitudinal study of outcome measures; (i) no use of medications that could affect hearing or cognition; and (j) completion of a signed medical clearance form, or waiver of such by the participant, and a signed informed-consent form.

The first of the two studies completed, referred to here as the linear ITE study, resulted in a total of 173 participants who completed all pretests and hearing aid outcome measures through the 1-month postfit interval. The second of the two studies, referred to here as the WDRC ITC study, was a smaller study and resulted in a total of 53 participants completing all measurements through the 1-month postfit interval. Given the larger pool of participants in the linear ITE study, the WDRC ITC participants served as the target sample for matching, and matching participants were drawn from the larger linear ITE study. Matching proceeded on an individual basis with exact matches required first for gender (male or female) and prior hearing aid experience (new or experienced), followed by a match to age within 5 years and then a match to binaural high-frequency pure-tone average (HFPTA; mean threshold at 1000, 2000, and 4000 Hz) within 5 dB. It was possible to find 53 of the 173 participants from the linear ITE study who met each of these matching criteria.

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The mean air-conduction hearing thresholds and loudness discomfort levels for each ear of the 53 participants in each group are plotted in Figure 1. Loudness discomfort levels were measured using the scaling categories and instructions described by Hawkins, Walden, Montgomery, and Prosek (1987) and an ascending approach with 5-dB step size. All audiologic measurements were obtained using ER-3A insert earphones. There were no significant differences (t tests, p > .05, adjusted for multiple comparisons) between groups in pure-tone thresholds or loudness discomfort levels for either ear or any frequency. Moreover, the two groups did not differ significantly (p > .05) on speech-recognition thresholds or word-recognition scores in either ear.

Regarding prior hearing aid use, 39 of the 53 (73.6%) participants in each group had not previously worn hearing aids. In addition, 18 of the 53 participants in each group, or 33.9%, were female. Finally, the mean age of the participants in the linear ITE sample was 74.0 years (SD = 6.7), and that of the WDRC ITC sample was 74.6 years (SD = 6.9), which was not a significant difference (p > .05).

Participants paid the full purchase price for the pair of hearing aids at the time of delivery (with only a few exceptions, who, in accord with customary clinical practices, purchased the aids on a deferred-payment plan).
Participants who returned for a series of follow-up measurements at the 2-week, 1-month, and 6-month postfit intervals were paid $150 per session. For both groups, all 53 participants returned for the 2-week and the 1-month follow-up sessions, but only 34 of the 53 participants in each group returned for the 6-month postfit testing.

**Procedure**

Following audiologic testing, participants returned for an extensive battery of cognitive, psychological, and auditory tests administered before hearing aid delivery. These sessions were completed over a series of five 90- to 120-min sessions. Once this prefit testing was completed, the participants returned for the initial fit and delivery of their hearing aids. For the linear ITE group, based on the previously obtained audiologic information and using the Hearing Aid Selection Program (HASP, Version 2.07; National Acoustics Laboratories [NAL]) fitting software, NAL–R targets, including corrections to targets for severe or profound hearing loss (Byrne, Parkinson, & Newall, 1990), were generated for each ear, and the corresponding circuit was selected and ordered. The HASP software returns a variety of targets, including real-ear insertion gain and full-on coupler gain. The latter was adjusted downward by the 10-dB reserve gain incorporated into the HASP software to create recommended coupler-gain values.

All hearing aids for this group made use of linear circuits with output-limiting compression and Class D amplifiers. All instruments were full-shell, ITE devices and included a telecoil switch on one instrument (determined by the wearer’s preference). Active tone (low-cut only) and output-limiting controls, adjustable select-a-vent venting, and wax guards were included on all devices. The volume-control wheels were marked by the manufacturer with a small white dot at the perimeter to provide a visual reference for its position and adjustment. All hearing aids were made by the same manufacturer.

Using real-ear insertion gain targets for the NAL–R prescription formula incorporated in the HASP fitting software, the clinician adjusted the settings of the controls and vent to achieve the closest match possible to target gain for a 60-dB SPL swept pure-tone signal with either Frye 6500 or Audioscan real-ear measurement equipment. Matching criteria were ±10 dB from 250 to 2000 Hz and ±15 dB at 3000 and 4000 Hz. If a match could not be obtained using these fairly broad matching criteria, the participant was not permitted to continue in the study. In fact, no participants were eliminated from the study for this reason, and the quality of the matches to target gain were considerably better than the broad exclusion criteria cited above. Figure 2 provides a comparison of the target and observed gain for each ear as measured in a 2-cm³ coupler following adjustment to target. As can be seen, there was, on average, a good match between the target gain and the gain measured in both ears. Regarding the individual matches to target gain, the root-mean-square error (RMSE) provides a measure of the difference between the measured and prescribed gain, regardless of the direction (sign) of the error. The RMSE between the observed and target gain ranged from 4.2 to 5.6 dB across frequencies in the right ear and from 4.3 to 4.9 dB across frequencies in the left ear.

Since the participants in the WDRC ITC group used hearing aids that made use of nonlinear circuitry, the NAL–R procedure (Byrne et al., 1990) followed with the linear ITE group could not be used to set the targets for gain and output. Instead, the FIG6 prescriptive approach (Killion & Fikret-Pasa, 1993) was used, and the hearing aid was adjusted to match the level-dependent frequency-gain characteristics prescribed by this approach. (At the time this study was initiated, the nonlinear NAL prescriptive method [NAL–NL1; Dillon, 1999] had not been finalized and could not be implemented for this group.)

The other primary difference between the hearing aids used by each subgroup was that the circuitry for the linear ITE group was packaged in a full-concha ITE shell, as noted above, as opposed to an ITC shell for those in the WDRC ITC group. Figure 3 contains a comparison between target gain and measured gain for each of three input levels (50, 70, and 90 dB SPL) and for each ear. In general, there was reasonable agreement between the targeted gain and that measured, but the measured gain was consistently 2–6 dB below target gain at each input level and in each ear at 2000, 3000 and 4000 Hz. Nonetheless, the desired level dependence of gain prescribed by the FIG6 formula is apparent in the measured gain for each ear. The RMSE between the observed and target gain ranged from 4.4 to 8.4 dB across frequencies in the right ear and from 4.2 to 7.3 dB across frequencies in the left ear. Note that comparison of the mean gain measured for the WDRC devices for the 70-dB input level in Figure 3 to the mean measured gain for the linear devices in Figure 2 reveals reasonably similar gain characteristics for moderate-level inputs in both devices.

For both groups, following the delivery of the hearing aids and their initial fitting by the clinician, a hearing aid orientation was conducted in which the following general topics were reviewed with each participant: (a) matters pertaining to the hearing aid purchase (user manual, warranty, 30-day trial period); (b) location and function of hearing aid components (e.g., microphone, volume control, battery door, telecoil switch, and wax guard); (c) hearing aid battery (e.g., size, type, insertion, and removal); (d) demonstration and practice in hearing aid insertion and removal; (e) demonstration and practice in care of hearing aids; and (f) counseling regarding benefits and limitations of amplification, communication strategies to optimize benefit, and instructions about the completion of a daily hearing aid usage diary. Participants were instructed to use their hearing aids at least 4 hr per day and to begin use in easier listening conditions (e.g., quiet or one-on-one conversation) when possible.

Each participant returned 2 weeks later for a follow-up. At the beginning of this session, gain measurements were again made in the coupler to evaluate the instruments and the aids were removed, inspected, and subsequently adjusted as needed to restore their function to that recorded in the initial session. The hearing aid usage diary was
collected, photocopied, and returned to the participants. The participants also were instructed to increase their minimum daily hearing aid usage to at least 6 hr.

Also during the follow-up, all unaided measures of speech recognition were completed. A total of 12 unaided speech-recognition scores were obtained. There were four basic test conditions, but in each condition, scores were obtained in the sound field from the right ear, the left ear, and then binaurally. For monaural testing, the nontest ear was occluded with a foam earplug. (Monaural unaided testing was included to permit examination of alternative definitions of objective hearing aid benefit in subsequent analyses not reported here.) The four test conditions were as follows: (a) CUNY Nonsense Syllable Test (NST; Levitt & Resnick, 1978), presented at an overall level of 65 dB SPL and an 8-dB speech-to-noise ratio (SNR) using the recorded multitalker babble from the Speech Perception in Noise (SPIN) test (Kalikow, Stevens, & Elliot, 1977); (b) the Connected Speech Test (CST; Cox, Alexander, Gilmore, & Pusakulich, 1988), presented at an overall level of 50 dB...
SPL in quiet; (c) the CST presented at an overall level of 65 dB SPL and an SNR of 8 dB using the recorded multitalker babble provided with the CST; and (d) the CST presented at an overall level of 80 dB SPL and an SNR of 0 dB. The particular combinations of speech level and SNR were selected to cover a range of anticipated real-world listening conditions, as suggested recently by Walden (1997) with the actual stimulus values based on the data of Pearsons, Bennett, and Fidell (1977). All speech materials were commercially available recorded versions. For the NST, the full 102-item, 11-subtest version was used, and for the CST, each score was based on two consecutive passages with each passage containing 25 key words for scoring. Different forms of the NST and different passages of the CST were used for each condition. The speech signal for all speech-recognition measurements was presented from a loudspeaker (Radio Shack Optimus 7) located 1 m in front of the participant at 0° azimuth and elevation, whereas the noise competition was delivered from an identical loudspeaker located 1 m behind the participant at 180° azimuth.
and 0° elevation. For the NST, the participant marked the syllable heard on a large-font answer sheet containing 7–9 alternatives that differed from the stimulus by only one phoneme. For the CST, before testing began, the participant was provided with the passage topic and was encouraged to guess if uncertain about what was heard. After each sentence of the passage, there was a pause in the presentation of the speech signal, and the participant repeated what had been heard. Using an orthographic representation of the passage, the experimenter proceeded to score the participant’s response using the highlighted key words.

Approximately 2 weeks later, the participant returned for the 1-month follow-up. The hearing aids were again examined, evaluated in the test box, and adjusted as needed to return their function to the target levels from the initial fitting session. Next, with this fixed, clinician-adjusted, volume-control setting, aided speech-recognition measures were obtained for the four test conditions outlined in the preceding paragraph, but only for the binaural listening condition. Thus, one NST and three CST scores were obtained in this session with the participant wearing both hearing aids, each adjusted in the test box to match the electroacoustic performance recorded in the initial fitting session. Test forms (NST) and passages (CST) not used previously were employed in this session.

In addition to aided speech-recognition measures, each participant completed six sets of surveys, questionnaires, or scales to provide subjective measures of benefit, satisfaction, usage, and sound quality. Measures were chosen to span a wide range of potential dimensions or aspects of hearing aid outcome while also having demonstrated reliability. The following five surveys or questionnaires were completed by each participant in the same order, using a pencil-and-paper response format: (a) Hearing Aid Performance Inventory (HAPI; Walden, Demorest, & Hepler, 1984); (b) Hearing Handicap Inventory for the Elderly (HHIE; Ventry & Weinstein, 1982); (c) MarkeTrak IV (Kochkin, 1997) Hearing Aid Satisfaction Survey (HASS); (d) closed-set version of the Glasgow Hearing Aid Benefit Profile (GHABP; Gatehouse, 1999); and (e) the Hearing Disability and Aid Benefit Interview (HDABI).

The GHABP contains four prototypical listening situations and four open-format listening situations that are established with the patient during an interview as being important listening situations. A shortened version of the GHABP was used in which only the four prespecified prototypical listening situations were used. Four patient-specific listening situations were not constructed.

In addition to the GHABP, this study used a precursor to the finished GHABP, the HDABI (Gatehouse, 1999). For this scale, 14 listening situations, which range from “listening to music” to “talking on the telephone” to “having a conversation with someone at a large noisy gathering,” are specified. For each of these hearing activities, three questions are asked: (a) how often does this situation occur for the individual (answered on a 5-point scale ranging from every day [1] to never [5]), (b) does the individual wear his or her hearing aids (answered on a 5-point scale ranging from always [1] to never [5]), and (c) how helpful are the hearing aids (answered on a 5-point scale ranging from very helpful [1] to hinders [5]). Thus, lower scores indicate greater frequency of occurrence, greater hearing aid use, and greater hearing aid benefit for these 14 listening situations.

The sixth and final subjective measure included in the 1-month follow-up made use of sound-quality judgments (JSQ) of Gabrielsson, Schenkman, and Hagerman (1988) and followed the procedures described by Narendran and Humes (2003) for aided listening. In this procedure, listeners were presented with acoustic stimuli in the sound field and rated the stimuli on eight different dimensions of sound quality (e.g., loudness, spaciousness, and brightness) on a 10-point scale. For each of the eight sound-quality dimensions, a one-sentence description of the dimension from Gabrielsson et al. (1988) was provided. Participants completed the quality ratings in the binaurally aided condition only and using the same configuration of loudspeakers as described previously for speech-recognition testing. Various speech and music stimuli were used for these quality judgments, with participants listening to 60 s of the material before completing a rating on one of the eight quality dimensions used. Thus, it took approximately 8 min to collect a complete set of quality ratings for a particular stimulus. There were two speech and two music conditions included in this session. For speech, the connected discourse from the Speech Intelligibility Rating (SIR) test (Cox & McDaniel, 1989) was presented at an overall level of 65 dB SPL in quiet and against the SIR noise competition at an SNR of 8 dB. The two music conditions comprised several 1-min segments of a commercial recording of classical music performed by a symphony orchestra. Each 1-min passage was equated in peak level (±2 dB) and in the variation of RMS sound levels (30 dB) within the passage. A calibration noise, matched to the peak level of the passages, was used to specify the presentation levels for the music materials. Music stimuli were presented at peak levels of 75 and 90 dB SPL (levels varying within a passage from 45–75 dB SPL and from 60–90 dB SPL, respectively). Music stimuli were always presented in quiet and from the loudspeaker located at 0° azimuth and elevation. Testing order for the JSQ was as follows: (a) practice trials for speech in quiet, randomly selected non-test SIR passages; (b) speech in noise; (c) speech in quiet; (d) practice with music at 82 dB SPL (level midway between those to be used); (e) music at 75 dB SPL peak level; and (f) music at 90 dB peak level. Volume-control position was adjusted to restore clinician-fit target gain, as measured electroacoustically in the test box, before performing the JSQ ratings.

Thirty-four participants from each group returned approximately 5 months later for the 6-month postfit measurements. Matching of gender, prior hearing aid experience, age, and HFPTA remained intact for these two smaller groups. All hearing aid outcome measures described above for the 1-month postfit interval were repeated, except for the measures of average hearing aid usage computed from the hearing aid diaries. In addition, data on the aided JSQ were available from only 26 of the participants in the linear ITE group.
Results

Figure 4 contains the unaided and aided measures of speech recognition, with the latter obtained at both the 1-month and 6-month postfit intervals. Means and standard deviations are shown for the linear ITE group and the WDRC ITC group. Independent-samples t tests revealed that none of the differences between groups were significant (p > .05, adjusted for multiple comparisons).

Figure 5 contains a similar display of total scores on the HHIE for each group. Although the HHIE scores for the linear ITE group were slightly and consistently higher than...
those of the WDRC ITC group, none of these differences were statistically significant (adjusted \( p > .05 \)).

Means and standard deviations for self-reported hearing aid benefit, as measured by the HAPI, are depicted for each group in Figure 6. A score of 2 on the HAPI corresponds to a label of helpful, and it can be seen that in general, both groups found their hearing aids to be helpful at both the 1-month and 6-month postfit intervals. In general, the hearing aids were also judged to be least helpful in noise by both groups. Once again, there were no significant (adjusted \( p > .05 \)) differences between groups at either postfit interval or on any of the HAPI scales.

The same results were obtained for the various scales of the GHABP, as shown in Figure 7. There were no significant differences (adjusted \( p > .05 \)) between the linear ITE and WDRC ITC groups in self-reported use, helpfulness, aided difficulty, satisfaction, or derived benefit (difference between the self-assessed communication difficulty for aided and unaided listening conditions). This was true again, moreover, for both the 1-month and 6-month postfit intervals.

Figure 8 summarizes the results for daily hours of hearing aid use calculated from entries in each participant’s hearing aid diaries (top only), as well as self-reported hearing aid use and helpfulness from the HDABI at both the 1-month (top) and 6-month (bottom) postfit intervals. No significant differences were observed between groups (adjusted \( p > .05 \)) for any of these measures.

Figure 9 contains the means and standard deviations for the HASS. Two scale scores were calculated from the 42 items constituting this measure, one derived from the 10 dispenser-related items (Dispenser) and the other from the...
remaining 32 items dealing with hearing aid features and the hearing aids’ performance in a wide variety of listening situations (Global). No significant differences (adjusted \( p > .05 \)) were observed between the linear ITE and WDRC ITC groups for either HASS scale or at either postfit interval.

Finally, the results for the aided JSQ are provided in Figures 10 and 11 for the 1-month and 6-month postfit intervals, respectively. Note that the mean aided JSQ ratings for each dimension of sound quality from the two groups of hearing aid wearers in this study for the speech stimulus in the quiet condition were in close agreement with the idealized norms from young adults under optimal listening conditions, with the possible exceptions of the stimuli in this study being judged as too soft and too bright in relation to these ideals. The mean JSQ ratings for both hearing aids departed still further from the ideal normative values when noise was added to speech, or when music of either moderate or high sound level was the stimulus. Most important, when a series of independent-sample \( t \) tests were performed, first for the 1-month postfit interval and then again for the 6-month postfit interval, none of the differences between the means of the linear ITE and WDRC ITC were found to be significant (adjusted \( p > .05 \)).

**Discussion**

The results from the wide range of outcome measures included in this study can be summarized succinctly in
terms of differences between the linear ITE and WDRC ITC groups: There were none. This was true for the measures completed at both the 1-month and 6-month postfit intervals. Thus, using an independent-group research design with participants matched for gender, prior hearing aid experience, age, and hearing loss failed to reveal any differences in hearing aid outcome for linear ITE instruments and two-channel WDRC devices. This was true, moreover, throughout a period of at least 6 months of hearing aid use.

Some prior laboratory comparisons of linear and multichannel WDRC hearing aids have observed superior speech-recognition performance with the compression systems than with linear hearing aids, although such comparisons have typically involved small sample sizes and measures of speech recognition that were obtained...
soon after the hearing aid fitting (e.g., Moore et al., 1992; Yund & Buckles, 1995b, 1995c). The effects observed, however, were generally small and primarily occurred at lower input levels or low SNRs. Also, additional outcome measures were seldom used in these studies. As noted previously, however, there has also been a suggestion that the superior performance of WDRC hearing aids over linear amplification increases over several months of hearing aid usage (Yund & Buckles, 1995a). Such an effect was not observed in the present study for postfit intervals of up to 6 months.

With regard to clinical, rather than laboratory, comparisons of single-channel linear and two-channel WDRC devices, the results of the present study were similar to those reported from a comparably sized sample of older adults (Humes et al., 1999). In the prior clinical study, a repeated measures design was used, but counterbalancing was not employed. All participants used linear ITC hearing aids in that study for 2 months first and, at a later date, used two-channel WDRC ITC devices for another 2 months. There were some differences between the two technologies, with the WDRC circuit demonstrating superior performance, but most of the differences were due to higher sound pressure levels in the listener’s ear canals that resulted from differences in the prescribed gain for each instrument and the use of a fixed volume control for testing (as in the present study). In the present study, there were smaller differences in the measured
The other primary difference between the results from this study and those from Humes et al. (1999) was that the previous study found that the WDRC circuit yielded significantly higher ratings than did the linear circuit on many dimensions of sound quality. Such an outcome was not observed in the present study. Since the repeated measures design of the prior study did not make use of counterbalancing and the WDRC devices were always the last ones tried, a response bias in favor of the WDRC circuit cannot be ruled out. In addition, whereas all participants were first-time hearing aid users before the 2-month trial of the linear devices in the earlier study, varying durations of prior hearing aid use (all had worn hearing aids previously for at least 2 months) were involved before the 2-month trial of the WDRC devices. So, the amount of prior hearing aid experience also differed between the two test conditions.

In a slightly smaller clinical study involving 25 participants in a within-subjects design, Newman and Sandridge (1998) obtained results similar to those in the current study using a wide array of outcome measures, including measures of speech-recognition performance, as well as self-reported benefit and satisfaction. Specifically, they failed to find any significant differences in outcome between a single-channel, linear BTE device and a two-channel, WDRC BTE instrument.
Finally, in another clinical study investigating performance differences between single-channel linear and two-channel WDRC hearing aids, Walden et al. (2000) used an independent-groups design with about 20 participants in each of the two groups. Small performance advantages were reported for the WDRC devices over the linear devices on measures of speech recognition and on self-reported measures of benefit. Although the ranges for age, hearing loss, and prior hearing aid experience incorporated in the selection criteria for each group were very similar, it is not possible to determine whether the groups used by Walden et al. (2000) were matched for any of these variables on either an individual or group basis. In fact, Walden et al. (2000) noted that there were group differences in hearing loss that tended to obscure some of the performance advantage associated with the WDRC devices in their study. In addition, there were other differences between studies, including the type of linear technology used, with input-dependent compression limiting used in Walden et al. (2000) and output-dependent compression limiting used in the present study.

Although differences were not observed between devices in this study, it should be emphasized that both devices exhibited positive outcomes. For example, aided speech-recognition performance was significantly higher than unaided speech-recognition performance for all materials and listening conditions, except for the CST at 80 dB SPL, and for both the linear ITE and WDRC ITC devices. In addition, HHIE scores improved significantly from prefit to postfit for both hearing aids. Furthermore, self-report measures of helpfulness generally indicated that the wearers of both devices found their hearing aids to be helpful (i.e., HAPI, GHABP, and HDABI), were satisfied with their devices (i.e., HASS and GHABP) and used their hearing aids regularly (i.e., hearing aid diaries, GHABP, and HDABI). Although these findings held for both the 1-month and 6-month postfit intervals, 19 of the 53 listeners in each group tested originally did not return for the 6-month follow-up, and there is no way to determine how their data might have affected the outcome measures obtained at that time.

Perhaps no differences were observed between the linear ITE and WDRC ITC groups on the various outcome measures at the 1-month and 6-month postfit intervals because the sample size was inadequate and there was insufficient statistical power as a result (Cohen, 1988). To assess this possibility, the size of the difference between means that was required for each outcome measure for statistical power of 80% (i.e., Type II error rate of 20%), a Type I error rate (or significance level) of 5%, and sample sizes of 53 and 34 participants for the 1-month and 6-month postfit intervals were calculated (assuming a two-tailed t test for equal-size independent groups). The poorest sensitivity to significance differences was observed for the CST tests in which differences of 12.6% and 15.9% would be required for detection at the 1-month and 6-month postfit intervals, respectively. In other words, there could be real differences between the linear ITE and WDRC ITC devices on the CST that were smaller than these values, and they would not be detected or identified in the statistical analyses performed in this study. For the NST and the total HHIE scores, the corresponding detectable differences between means were 9.3% and 11.7% at the 1-month and 6-month postfit intervals, respectively. For the HAPI scales, the HASS, the GHABP, and the HDABI, scale differences of about half of a scale unit (0.55) were detectable with these analyses at either postfit interval. Finally, differences in mean JSQ ratings of 1.0 and 1.2 units were detectable in this study at the 1-month and 6-month postfit intervals, respectively. In summary, with the possible exception of the CST measures, the statistical power was adequate to detect real or clinically significant differences in performance between the linear ITE and the WDRC ITC groups, yet none were observed.

In conclusion, no significant differences were observed in this study between binaural, single-channel, linear, Class D, ITE hearing aids with output-limiting compression and binaural, two-channel, WDRC ITC hearing aids on a wide variety of outcome measures when each technology was evaluated by a separate group of 53 older hearing aid wearers matched for age, gender, hearing loss, and prior hearing aid experience. More important, however, both technologies provided significant improvements in speech-recognition performance relative to unaided performance and were reported by the users to be helpful. Further, the participants in both groups indicated that they were generally satisfied with their devices and used them several hours per day.

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