1997

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J Am Acad Audiol 8: 280–293 (1997)

Differences in Performance between Oticon MultiFocus Compact and ReSound BT2-E Hearing Aids

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Abstract

Differences in performance were evaluated between binaural fittings of the Oticon MultiFocus (MF) and ReSound BT2-E on 25 hearing-impaired subjects across two sites. Subjects were initially fit using each manufacturer's algorithm and adjustments were made at 1 week based on subjects' responses to diary questions. Performance was assessed after a 4- to 6-week trial period with each hearing aid set using the Speech Perception in Noise (SPIN) test administered at 50, 65, and 80 dB SPL, the Abbreviated Profile of Hearing Aid Benefit (APHAB) questionnaire, loudness judgments of female connected discourse at 65 and 80 dB SPL, and an overall preference selection. The MF yielded significantly better SPIN scores at 50 and 65 dB SPL, while the BT2-E yielded a significantly better score at 80 dB SPL. No statistically significant differences were found in the APHAB benefit scores between the hearing aid sets, but both sets were significantly better than the subjects' own hearing aids on three of the four subscales. The MF produced slightly higher mean loudness judgments at both input levels than the BT2-E. Finally, 12 subjects preferred the BT2-E, 10 subjects preferred the MF, and three subjects stated no preference. The results are discussed in terms of audiogram effects on preference and effects of differences in signal processing approaches between the devices.

Key Words: Abbreviated Profile of Hearing Aid Benefit (APHAB), MultiFocus, ReSound BT2-E, Speech Perception in Noise (SPIN)

Abbreviations: AGC = automatic gain control, APHAB = Abbreviated Profile of Hearing Aid Benefit, AV = aversiveness to sounds, BILL = base increase at low levels, BN = background noise, BTE = behind the ear, Cf = crossover frequency, EC = ease of communication, HB = high band, HP = high predictability, IHAFF = Independent Hearing Aid Fitting Forum, LB = low band, MF = MultiFocus, RV = reverberation, SNR = signal-to-noise ratio, SPIN = Speech Perception in Noise, TILL = treble increase at low levels, WDRC = wide dynamic range compression

A substantial number of multichannel hearing aids with relatively complex approaches to signal processing have recently appeared on the market. Two of the more interesting behind-the ear (BTE) multichannel hearing aids are the Oticon MultiFocus (MF) Compact and the digitally programmable ReSound Encore (BT2-E). Although both use two-channel processing, the MF has a fixed crossover frequency (Cf) at 1600 Hz, whereas the BT2-E has a Cf that can be programmed between 400 and 4700 Hz in ½-octave band steps. More importantly, in the low-frequency channel (i.e., frequency range *below* Cf), the MF provides

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wide dynamic range compression (WDRC) for moderate input levels, but at very high input levels, only a minimal amount of gain necessary to overcome average insertion loss is provided. On the other hand, the low-frequency channel of the BT2-E can be programmed to provide processing ranging from essentially linear (1:1) to WDRC (3:1), although the manufacturer's algorithm frequently results in more linear processing. The high-frequency channel (i.e., frequency range *above* Cf) of the MF provides linear amplification with output compression limiting, while in the BT2-E, the high-frequency channel usually is programmed to provide WDRC. Another difference between these two hearing aids is the approach to the initial fitting. Although the MF is fitted with manually adjusted trimpots using only pure-tone thresholds, the BT2-E fitting is accomplished via a computerized algorithm that can include measurement of individual loudness growth. Neither the MF nor BT2-E has a user-adjustable volume control.

Several reports on the performance of the MF have been encouraging. In clinical trials, the MF has been reported to perform better than a conventional single-channel linear hearing aid on measures of speech recognition in noise and subjective questionnaires (Parving, 1993; Schuchman et al, 1996). In addition, Niklasson-Lovbacka (1994) compared the performance of the MF to a K-Amp (Killion, 1990), a popular single-channel TILL processor (treble increase at low levels; Killion et al, 1990). Her data showed a trend toward better speech performance in noise with the MF, although results failed to reach statistical significance. However, a slightly greater percentage of the subjects elected to keep the K-Amp rather than the MF when given the choice.

The performance of the ReSound hearing aid has been reported in a number of studies. Moore et al (1992) evaluated ReSound signal processing on 20 experienced hearing aid users having moderate sensorineural hearing loss. The hearing aids were programmed to provide linear amplification in one memory and two-channel compression in the second memory. The subjects were not allowed to increase or decrease the amplification once the overall gain was adjusted to the most comfortable loudness level (MCL). Speech recognition was measured in quiet at input levels of 50, 65, and 80 dB SPL, as well as in a 12-talker babble presented at a +3 dB signal-to-noise ratio (SNR). For speech in quiet, word recognition scores for the two processing conditions were similar for the 65 and 80 dB SPL input levels. However, at the 50 dB SPL input condition, the two-channel compressor condition resulted in a mean score of 85 percent, whereas the scores for the linear mode averaged less than 40 percent. The improved word recognition score for the 50 dB SPL condition favoring two-channel compression may have been related to the presence of less gain available to the subjects for linear signal processing because subjects were not allowed to change gain in response to varying input levels. The results for the linear processing for the 50 dB SPL level might have been different if the subjects were allowed to change gain in reaction to the input level of the signal. For speech recognition in noise, the mean score with two-channel compression was greater than 60 percent, while the mean score for the linear condition was less than 30 percent. In another study, Benson et al (1992) compared ReSound with linear, single-channel hearing aids on 18 hearing-aid users. Mean performance with ReSound was superior to the single-channel linear hearing aids on a number of measures including greater functional gain, width of the dynamic range, questionnaire responses, and speech recognition for sentences at 50 and 65 dB SPL. However, there was no significant difference on speech recognition at 80 dB SPL.

Despite the fact that the signal processing used in the MF and BT2-E results in different frequency/gain responses as the input level changes, they have become direct competitors for hearing-impaired patients having similar hearing loss. Unfortunately, there have been no studies directly comparing the performance of the MF with the BT2-E, leaving the dispenser with little guidance in the decision-making process regarding which hearing aid might result in better performance and user acceptance for a given patient. Therefore, the current study was undertaken with the goal of determining if performance differences could be demonstrated between these two hearing aids and, if so, whether subject factors might be identified that would serve as predictors of performance.

Procedures

Subjects

Twenty-five adults with mild-to-moderate severe bilateral symmetrical sensorineural hearing loss (ANSI, 1989) were evaluated at two sites (12 subjects at Washington University

School of Medicine in St. Louis, 13 subjects at Indiana University School of Medicine in Indianapolis). Approximately one half of the subjects at each test site were male and one half were female. Ages of the subjects ranged from 26 to 80 years, with a mean age of 63 years.

For each subject, the average hearing loss in each ear for 250, 500, and 1000 Hz was between 35 and 65 dB HL, and the average hearing loss for 2000 and 4000 Hz was between 45 and 75 dB HL. Hearing losses between ears were symmetrical within 10 dB at all frequencies for a given subject. Figure 1 reports the mean thresholds and one standard deviation for the 25 subjects. Normal middle ear function was assessed via tympanometry using a 220-Hz probe tone. All subjects had prior experience with binaural amplification for at least 6 months, and most for many years. However, no subject had prior experience with either the MF or ReSound hearing aids. At the time of the study, 21 subjects were wearing single-channel linear hearing aids (some with peak clipping and some with output compression limiting), two were wearing single-channel automatic gain control (AGC) hearing aids, and two were wearing multichannel hearing aids from another manufacturer. Most of the subjects' current hearing aids had been fit at the authors' clinics. All of the subjects' current hearing aids were judged by the authors to be appropriate for the magnitude and configuration of the hearing loss, except for one subject whose current hearing aids were judged to be somewhat less than optimal. In addition, all current hearing aids were evaluated electroacoustically to verify that they were functioning well at the time of the study.

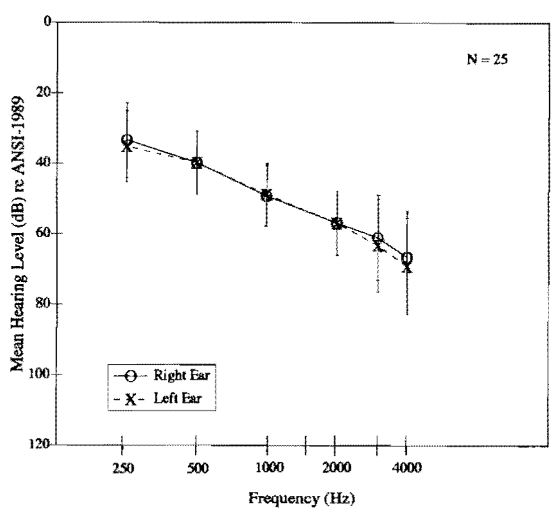


Figure 1 Means and standard deviations of hearing levels (dB HL) at 250–4000 Hz for the right (O–O) and left (X–X) ears of the 25 subjects.

Hearing Aid Fittings

All subjects were fit binaurally with the BT2-E and MF hearing aids and wore each hearing aid set for a minimum of 6 hours daily for a period of 4 to 6 weeks. The order of fitting of the hearing aids was counterbalanced across the subjects. The earmold style and tubing selected were considered appropriate for the magnitude and configuration of hearing loss. In most cases, subjects were fit with select-a-vents and/or with 3-mm or 4-mm Libby horns. The same earmold was used for a given subject across both hearing aid sets.

For the initial settings of the MF, the pure-tone thresholds were entered onto the worksheet provided by the manufacturer. Based upon the average hearing loss at 250, 500, and 1000 Hz, the low-frequency potentiometer (LF-HTL) was adjusted between 35 and 65 in 5-dB steps. Based upon the average hearing loss at 2000 and 4000 Hz, the high-frequency gain (HF-HTL[G]) and power (HF-HTL[P]) potentiometers were adjusted between 45 and 75 dB in 5-dB steps. In addition, the worksheet specified that the high-frequency settings should be at least 15 dB greater than the low-frequency setting to prevent the effects of upward spread of masking. The LF-HTL potentiometer adjusts the gain, output, and compression characteristics of the low-frequency channel. The HF-HTL(G) potentiometer adjusts the gain in the high-frequency channel, while the HF-HTL(P) potentiometer adjusts the high-frequency maximum power output.

The initial settings for the BT2-E were based upon the subject's audiometric and loudness growth measurements. The pure-tone thresholds at 250 to 8000 Hz were entered into the ReSound P[3] programmer. Also, subjects completed the loudness growth in octave band (LGOB) test for each ear using the manufacturer's instructions. The initial settings were based upon the "Audio + LGOB" algorithm provided by the P[3] programmer. This algorithm selects the Cf, the gain for soft (50 dB SPL) and loud (80 dB SPL) input levels for both the low band (LB) and high band (HB) on either side of Cf, based on both the audiometric thresholds and LGOB data. The difference in the selected gain between the 50 and 80 dB SPL inputs determines the compression ratio (CR) for each channel.

The subjects wore the hearing aids at these manufacturer-specified settings for 1 week and then returned for parameter adjustment based on their subjective impressions. When adjusting the MF, the experimenters closely followed the Oticon "Fine Tuning" guidelines based upon the subject's entries in the MF diary provided to each subject. The adjustments to one or more of the three potentiometers were based upon subject comments related to *loudness* (too loud, too weak), *listening range* (hears too many unwanted sounds, problems listening to TV/radio or hearing people far away), *tonal balance* (tinny, muffled/barrel-like sound), *sound quality* (distortion, hollowness) and *other* (e.g., feedback). When adjusting the BT2-E, subject comments on a similar diary and manufacturer's recommendations regarding changing gain in each of the four quadrants (LB_{50}, LB_{80}, HB_{50}, HB_{80}) were closely followed. The subjects then wore each set of hearing aids for 3 to 5 more weeks with the adjusted parameters.

Speech Perception in Noise (SPIN) Test

After the 4- to 6-week trial period with each hearing aid set, the revised-Speech Perception in Noise (SPIN; Cosmos Distributing Inc., Forms 1-8) was administered. The SPIN has been described in great detail (Kalikow et al, 1977; Bilger et al, 1984). It includes 50 sentences in each list for which the subject's task is to repeat the final word. One half of the sentences are called "low predictability" (LP) items, which supply no contextual cues to identification of the final word, and one half are called "high predictability" (HP) items, which have contextual cues. For this study, the sentences were presented at input levels of 50, 65, and 80 dB SPL, as measured by a sound level meter placed at ear level and one meter from a loudspeaker at 0° azimuth with the head absent. The 12-talker babble noise stimulus was presented from the same loudspeaker, but at a level 8 dB lower than each speech presentation level, thus maintaining a +8 dB signal-to-noise ratio (SNR).

Abbreviated Profile of Hearing Aid Benefit (APHAB)

The APHAB is a 24-item subjective assessment scale that reportedly measures perceived benefit from amplification (Cox and Alexander, 1995). Each item is a statement, and the subject indicates the proportion of time that the statement is true, using a 7-point scale. The subject responds to each question on the basis of how they believe their performance is unaided and aided for each specified listening situation. Hearing aid "benefit" (in percent) is defined as the difference between the unaided and aided problem scores. The APHAB is scored for four subscales, which include *ease of communication* (EC), *reverberation* (RV), *background noise* (BN), and *aversiveness to sounds* (AV). The APHAB was administered with reference to the subject's own hearing aids at the beginning of the study and at the end of the 4- to 6-week trial period with each hearing aid set.

Loudness Judgments for Speech

Following the 1-week follow-up adjustments, aided loudness judgments were measured for female connected discourse presented at input levels of 65 and 80 dB SPL. Using the IHAFF protocol (Van Vliet, 1995), in which a statement and number is applied to different loudness judgments, the authors determined if the 65 dB SPL input was judged by the subject to be "comfortable, but slightly soft (#3)," "comfortable (#4)," or "comfortable, but slightly loud (#5)." With the 80 dB SPL input, the authors determined if the loudness was judged to be "loud, but O.K. (#6)" or "uncomfortably loud (#7)."

Overall Preference

Finally, after the subjects had worn each hearing aid set for the trial period, they were interviewed to determine user preference. Several questions were asked consistently across subjects. First they were asked, "If you had a choice to purchase either set of hearing aids, which would you purchase (or do you like both equally well)?" Note that subjects were not given any pricing information on the hearing aids in order to avoid influencing their response based on a financial decision. Second, if they did have a preference for one hearing aid set over the other, they were asked if the preference was slight or strong. Finally, they were asked to comment on why they preferred one hearing aid set over the other or to comment on any perceived differences between the two hearing aid sets.

RESULTS AND DISCUSSION

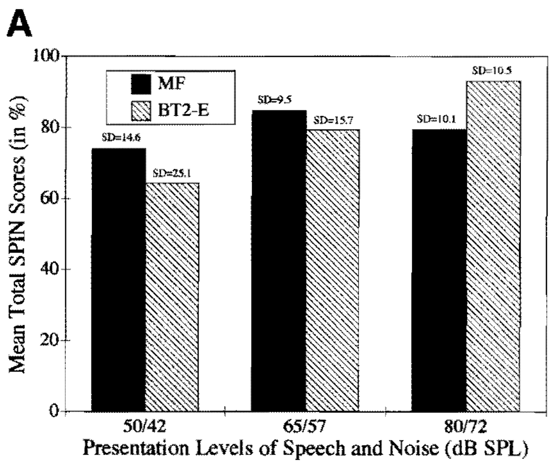
SPIN

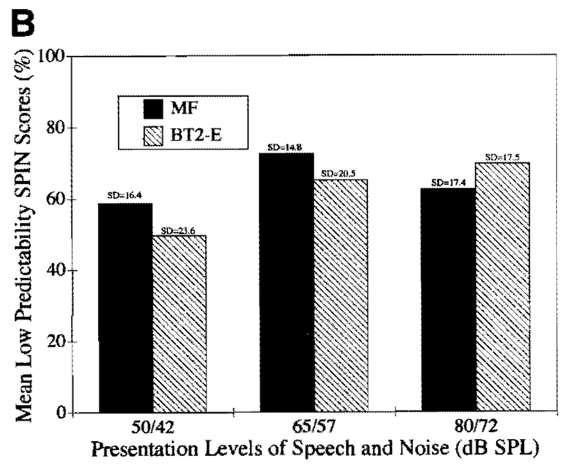
SPIN percent correct scores were arcsine-transformed prior to statistical analysis to normalize the variance (Studebaker, 1985).

Means and standard deviations of total LP-item and HP-item SPIN scores for each hearing aid set and stimulus input level are shown in Figure 2, A–C. Running a separate statistical analysis for total, LP-item, and HP-item scores, a 2 × 3 (hearing aid set by presentation level) analysis of variance (ANOVA) with repeated measures revealed the following results. For the total scores, there was a significant main effect of hearing aid ($F = 4.29$; df = 1,24; $p < .05$) and of stimulus level ($F = 24.16$; df = 2,48; $p < .0001$), as well as a significant interaction ($F = 14.19$; df = 2,48; $p < .0001$). Simple effects analysis holding stimulus level constant revealed that the MF yielded significantly better performance at the 50 and 65 dB SPL stimulus levels than did the BT2-E, but that the BT2-E yielded significantly better performance than the MF at the 80 dB SPL stimulus level. With hearing aid held constant, examination of simple effects followed by Tukey post hoc comparisons revealed that, for the BT2-E, the mean score at 50 dB SPL was significantly poorer than at 65 and 80 dB SPL, while 65 and 80 dB SPL did not differ significantly from each other. For the MF, the means at all three stimulus levels were significantly different from each other.

For the LP-item scores, there was a significant main effect of stimulus level ($F = 20.78$; df = 2,48; $p < .0001$) but not of hearing aid; however, there was also a significant interaction ($F = 10.17$; df = 2,48; $p < .0003$). With hearing aid held constant, simple effects analysis followed by post hoc Tukey comparisons revealed that the performance of the MF at 65 dB SPL was significantly better than performance at either 50 or 80 dB SPL, but that performance at 50 and 80 dB SPL did not differ significantly from each other. For the BT2-E, performance at 50 dB SPL was significantly poorer than at 65 and 80 dB SPL, but 65 and 80 dB SPL did not differ significantly.

For the HP-item scores, there was a significant main effect of hearing aid ($F = 5.30$; df = 1,24; $p < .04$) and of stimulus level ($F = 12.96$; df = 2,48; $p < .0001$), and also a significant interaction ($F = 7.25$; df = 2,48; $p < .002$). With stimulus level held constant, simple effects analysis revealed that the MF produced significantly better performance at 50 dB SPL than did the





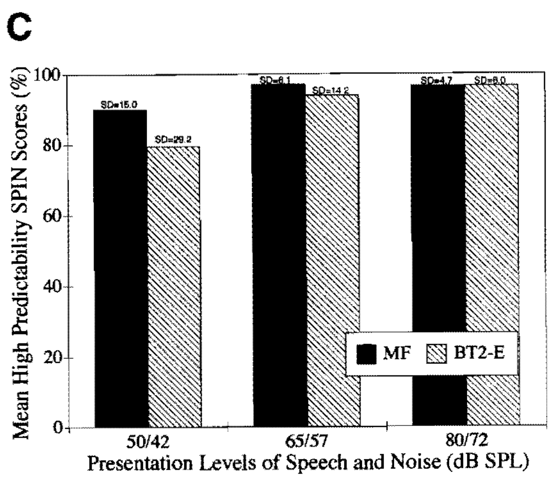


Figure 2 Means and standard deviations of SPIN scores for the two hearing aid sets at the three speech/noise presentation levels. Part A is total scores, part B is LP-item scores, and part C is HP-item scores.

BT2-E, but no other differences were significant. With hearing aid held constant, there was significantly poorer performance at 50 dB SPL compared with 65 and 80 dB SPL for both hearing aid sets, and no difference in performance at 65 versus 80 dB SPL within either set.

APHAB

Means and standard deviations of the APHAB benefit scores for each subscale with the MF, BT2-E, and the subjects' own hearing aids are shown in Figure 3. Note that a higher, positive score indicates greater benefit for the EC, RV, and BN subscales, but that a less negative value indicates greater benefit for the AV subscale (i.e., amplified sounds are less aversive). A one-way ANOVA with repeated measures on hearing aid set (including the subjects' own hearing aids) on each APHAB subscale revealed the following results. For the EC ($F = 12.33$; df = 2,24; $p < .0001$), RV ($F = 11.76$; df = 2,24; $p < .0001$), and BN ($F = 15.46$; df = 2,24; $p < .0001$) subscales, there were significant effects of hearing aid. Tukey post hoc comparisons revealed that the MF and BT2-E were both judged to be significantly better than the subjects' own hearing aids on each of these three subscales, but that the mean benefit scores between the MF and BT2-E were not significantly different from each other. For the AV subscale, there was no significant effect of hearing aid.

Cox and Alexander (1995) reported that a difference of ≥10 percent between the EC, RV, *and* BN subscales (i.e., the 10% difference needs to be present for all three subscales) for one hearing aid condition relative to another hearing aid condition (i.e., either experimental aid and the subjects' own aids) for an individual can occur by chance alone in only 4 percent of observations.

Table 1 reports the difference in APHAB benefit scores between the MF and BT2-E hearing aids and the subjects' own aids for the EC, RV, and BN subscales for the 25 subjects. The rows in which the values are in bold and underlined by a single line show at least a 10 percent difference between the experimental aids and the subjects' own aids. The rows in which the values are in bold, italicized, and underlined by a double line show at least a 5 percent difference between the experimental aids and the subjects' own aids. Cox and Alexander (1995) reported that a difference of ≥5 percent between the EC, RV, *and* BN subscales for one hearing aid

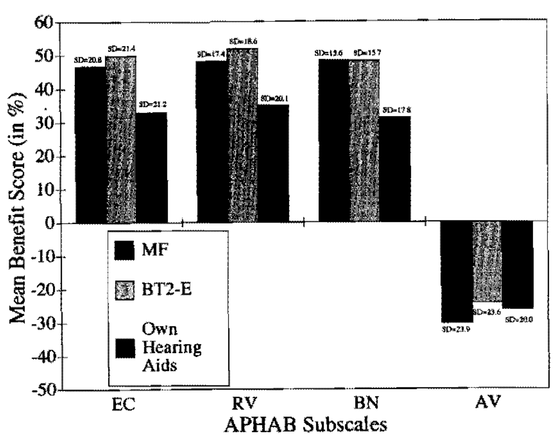


Figure 3 Means and standard deviations of the benefit scores for the EC, RV, BN, and AV subscales of the APHAB for the two hearing aid sets and the subjects' own aids.

Table 1 Individual Differences in the APHAB Benefit Score between the MF or BT2-E Hearing Aids and the Subjects' Own Aids on the EC, RV, and BN Subscales

	MF			*BT2-E*		
Subject	*EC*	*RV*	*BN*	*EC*	*RV*	*BN*
1	**22.8**	**10.5**	**17.1**	12.2	–17.8	–1.7
2	**26.5**	**21.7**	**33.1**	**41.8**	**29.0**	**35.1**
3	***12.7***	***16.8***	***8.5***	4.5	6.5	18.6
4	6.5	2.1	14.8	8.7	–6.4	8.2
5	2.0	10.3	2.4	34.9	20.5	–8.5
6	–3.0	–4.0	15.0	–14.7	–0.2	29.0
7	–8.0	4.2	29.2	***8.7***	***8.4***	***31.2***
8	–18.8	8.3	39.5	–19.2	12.8	18.8
9	**14.5**	**20.6**	**46.2**	2.9	48.0	43.3
10	–4.0	14.5	–23.0	***5.5***	***41.5***	***8.2***
11	***6.7***	***23.3***	***29.5***	0.5	40.0	33.9
12	4.4	–16.3	–16.8	8.2	12.5	–22.8
13	0.3	22.9	18.9	0.0	9.7	16.6
14	**22.2**	**27.3**	**22**	**24.9**	**21.4**	**11.4**
15	**33.7**	**34.5**	**15.9**	**20.4**	**12.6**	**10.2**
16	56.1	–2.3	14.6	53.7	–2.0	14.6
17	**39.5**	**60.0**	**43.3**	**59.8**	**60.2**	**49.5**
18	**23.5**	**60.3**	**54.2**	**31.8**	**58.5**	**56.2**
19	**33.6**	**31.4**	**31.7**	**33.5**	**29.5**	**41.9**
20	22.2	1.3	1.2	**61.0**	**15.8**	**27.7**
21	8.5	2.2	–14.1	6.5	10.2	0.2
22	39.3	–7.9	14.0	16.2	0.0	22.5
23	**15.7**	**12.3**	**14.4**	–3.8	6.3	–8.3
24	–2.0	–10.3	6.5	2.0	–1.8	–8.0
25	–0.4	–12.4	2.0	14.1	–0.2	6.3

– = performance with own aid was judged to be better than experimental aid; + = performance with experimental aid was judged to be better than own aid.

Values in bold and with single underline show at least a 10% difference between the experimental aids and subjects' own aids; values in bold, italicized, and with double underline show at least a 5% difference between the experimental aids and the subjects' own aids.

condition relative to another hearing aid condition (i.e., either experimental aid and the subjects' own aids) for an individual can occur by chance alone in only 11 percent of observations. Thus, according to Cox and Alexander (1995), there is an 89 percent probability that the improved benefit by the users in this study was a "true" perceived benefit. In looking at Table 1, for the MF, 11 of 25 subjects (44%) showed a 5 percent or 10 percent difference in all three subscales, whereas, for the BT2-E, 9 of 25 subjects (36%) showed a 5 percent or 10 percent difference in all three subscales. Further, for the MF hearing aids, 5 additional subjects showed a 5 percent or 10 percent (subjects 4, 8, 13, 16, and 22) difference on two of the three subscales and, for the BT2-E hearing aids, 12 additional subjects showed a 5 percent or 10 percent (subjects 3–5, 8, 9, 11–13, 16, 21, 22, and 25) difference on two of the three subscales.

Table 2 Summary of Comments Concerning the MF and BT2-E Fittings and the Preferred Hearing Aid for Each Subject

Subject	*Current Aid*	*MF*	*BT2-E*	*Preferred*
1	Linear ITE	Too loud, tinny	Better sound quality, better comfort for loud sounds	BT2-E
2	Linear ITE	Too loud, poor sound quality, sharp sound quality, words unclear, high tones prominent	Sound quality more pleasing	BT2-E
3	Linear ITC	Feedback, background noise is too prominent	More comfortable and natural, slight edge in understanding speech	BT2-E
4	2-channel AGC ITE	Too loud, including own voice	More comfortable/natural, handled louder sounds better	BT2-E
5	Linear ITC	None	Easier to listen with	BT2-E
6	2-channel AGC ITE	None	Better at reducing noise, TV too soft and muffled	BT2-E
7	Linear CIC	Background noise too loud, speech louder and clearer	None	MF
8	Linear BTE	Background sounds too loud	Better in noise, but speech too soft	BT2-E
9	Linear ITE	Loud, sharp, harsh, own voice bothersome	More natural, loudness more pleasing	BT2-E
10	1-channel AGC, ITC	Too loud, sharp	More comfortable loudness	BT2-E
11	Linear ITE	None	Not as overwhelming in background noise	BT2-E*
12	2-channel AGC, ITE	Louder, clearer	None	MF
13	Linear ITE	Clearer speech, especially in noise	Not as comfortable listening	MF
14	Linear ITC	Tinny, better for quiet speech and bird songs	Better in louder environments or if there are competing speakers	Neither
15	Linear ITC	Physically easier to manipulate	None	MF
16	Linear ITE	Louder, better for too soft or "mumbled" speech	Left ear louder than right	MF
17	Linear ITE	Feedback	Just felt "heard better"	BT2-E
18	Linear ITE	Both hearing aids were equally good		Neither
19	Linear ITE	Clearer, better sound quality	Too soft	MF*
20	Linear ITE	Too loud	Handled loud sounds and noise better	BT2-E
21	Linear ITE	Both hearing aid sets were equally good		Neither
22	Linear ITE	Clearer, better sound quality	None	MF
23	Linear ITE	Clearer speech	Muffled	MF
24	Linear ITE	Loud enough, speech clearer	Noise too loud	MF
25	Linear ITE	None	Speech unclear	MF

*Strong (rather than slight) preference.

Loudness Judgments for Speech

For female connected discourse at 65 and 80 dB SPL, median loudness judgments using the categories from the IHAFF protocol were slightly greater for the MF than the BT2-E at both presentation levels. At 65 dB SPL, the median judgment was 4.3 for the MF versus 3.8 for the BT2-E. At 80 dB SPL, the median judgment was 6.2 for the MF versus 5.8 for the BT2-E. These results agree with the results of the AV subscale of the APHAB where the mean benefit score for the AV subscale was lower for the BT2-E.

Overall Preference

At the conclusion of the study, 12 of the 25 subjects chose the BT2-E as their preferred hearing aid set (i.e., the one they would choose to purchase), 10 chose the MF, and 3 stated no preference for either hearing aid set (liking both equally). Only 2 of the 22 subjects who did select one hearing aid set over the other had a strong rather than slight preference, one for the BT2-E and one for the MF. The majority of subjects stated that it was difficult to decide between the MF and BT2-E hearing aid sets, but most commented on the superiority of both hearing aid sets over their current hearing aids. Examination of preference as a function of order of hearing aid set worn revealed no effect (i.e., approximately one half of the subjects selected the first hearing aid set worn and one half selected the second hearing aid set worn).

Table 2 lists, for each subject, their current hearing aid type, their comments (if any) regarding the MF and BT2-E, and their selection for the preferred hearing aid set. Note that, with some exceptions, subjects who selected the MF tended to comment that the MF made speech "loud enough," " provided clearer speech," and was "better for soft speech." Subjects selecting the BT2-E tended to comment that the BT2-E provided "better sound quality," "greater listener comfort," " sounded more natural," and was "better in background noise," or that the MF was "too loud" or had a "sharp/tinny" sound quality. As there were persisting complaints of problems such as a lack of balance in the amplification between ears and feedback from the amplification despite our best efforts at the 1-week follow-up session, the need for more than one follow-up session with at least some (if not all) hearing aid patients is clear.

Audiogram Effect

When the data were examined to determine if any audiometric factors might predict preference choice, there appeared to be an audiogram effect. As shown in Table 3, the mean audiogram for subjects who selected the MF shows a

Table 3 Mean Audiogram and Standard Deviations by Hearing Aid Preference Group

		Frequency (Hz)					
Preference	*Ear*	*250*	*500*	*1000*	*2000*	*3000*	*4000*
No Preference (N = 3)	Right ear						
	Mean	30.0	35.0	41.7	48.3	58.3	66.7
	SD	5.0	5.0	2.9	2.9	14.4	20.8
	Left ear						
	Mean	31.7	35.0	43.3	51.7	60.0	66.7
	SD	5.8	5.0	7.6	10.4	5.0	12.6
Prefer BT2-E (N = 12)	Right ear						
	Mean	32.9	38.8	49.2	58.8	61.7	67.5
	SD	9.2	7.7	8.8	6.8	12.1	11.2
	Left ear						
	Mean	34.6	38.8	49.6	55.8	60.0	65.8
	SD	9.2	9.8	9.9	7.9	8.0	11.3
Prefer MF (N = 10)	Right ear						
	Mean	36.5	43.5	53.0	59.5	63.5	69.0
	SD	13.6	10.6	8.6	9.9	12.5	14.7
	Left ear						
	Mean	37.5	43.5	60.0	59.5	67.5	73.0
	SD	11.8	8.5	7.5	9.9	18.4	16.3

Table 4 Means and Standard Deviations of Dynamic Ranges (Upper minus Lower Limit of the LGOB Test) by Hearing Aid Preference Group

		Frequency (Hz)			
Preference	*Ear*	*500*	*1000*	*2000*	*4000*
Prefer MF	Right ear				
(N = 10)	Mean	43.3	35.2	27.8	26.4
	SD	8.9	11.4	11.3	6.5
	Left ear				
	Mean	43.9	38.9	31.1	23.3
	SD	11.0	11.2	8.2	9.5
Prefer BT2-E	Right ear				
(N = 12)	Mean	48.3	42.4	36.0	32.4
	SD	13.2	15.8	15.1	19.0
	Left ear				
	Mean	53.4	44.0	38.4	33.4
	SD	19.0	15.4	15.3	17.9
No Preference	Right ear				
(N = 3)	Mean	36.0	39.0	35.0	24.7
	SD	1.7	0.0	3.5	7.5
	Left ear				
	Mean	38.7	44.0	31.0	22.3
	SD	8.1	10.4	3.5	04.6

more severe hearing loss than the mean audiogram for subjects who selected the BT2-E (particularly in the low-frequency region), with the three subjects who had no preference showing the least severe mean audiogram. Table 4 shows the mean and standard deviation of dynamic ranges by preference grouping, measured as the difference between the upper and lower limits (loud to very soft) on the LGOB test for each frequency. The mean dynamic ranges were smaller for those subjects who selected the MF than for those subjects who preferred the BT2-E, consistent with the fact that those who selected the MF generally had the more severe hearing loss.

The data were also examined for any bias between the two sites, and an apparent difference was observed in selection of preferred hearing aid set. Ten of the 12 subjects at the St. Louis site preferred the BT2-E, while only two preferred the MF. In contrast, 8 of the 13 subjects at the Indianapolis site preferred the MF, only 2 preferred the BT2-E, and 3 reported no preference for either hearing aid set. Further examination of the data revealed, however, that there was also a difference between the sites in audiograms of the subjects, which was probably a factor in the preference differences. Although both sites used the same subject selection criteria, the hearing losses of the subjects in the Indianapolis site tended to be more severe than those of the subjects at the St. Louis site with a few exceptions.

There was only one notable exception to this audiogram by preference grouping: one of the subjects at the Indianapolis site (#20) did fall into the more severe audiogram range but selected the BT2-E as his preferred hearing aid set. He stated that the MF hearing aids were uncomfortably loud despite reduced gain at the 1-week follow-up; notably, this individual also showed the steepest loudness growth function on the LGOB test of all of the subjects.

Analysis by Hearing Aid Preference Grouping

Given the notable audiogram effect on the site data, rather than further analyzing by site, the performance data were analyzed by hearing aid preference grouping (N = 12 subjects who preferred the BT2-E and N = 10 subjects who preferred the MF).

A 2 × 3 ANOVA with repeated measures (hearing aid set by stimulus level) on the SPIN results using hearing aid preference as a grouping factor revealed no significant effect of the grouping factor for either the total scores or LP-item scores. For HP-item scores, however, there was a significant main effect of the grouping factor ($F = 7.78$; $df = 1, 50$; $p < .02$), but no significant interaction with hearing aid. Examination of means revealed that the HP-item scores, collapsed across hearing aids and stimulus level, were significantly better for those subjects who chose the BT2-E (mean = 97%, SD = 0.04) than those who chose the MF (mean = 87%, SD = 0.14). Similar analysis of the APHAB results with preference as a grouping factor revealed no significant effect of the grouping factor on any of the subscales. Loudness judgments were also examined by preference group and revealed the same pattern as previously noted, that is, regardless of preference grouping, the MF was judged to be slightly louder, on average, across both input levels, than the BT2-E.

Figures 4, 5, and 6 show the average HA-1 2-cc coupler frequency/gain responses by preference group for the MF (A) and BT2-E (B) hearing aids for stimulus inputs of 50, 60, 70, and 80 dB SPL using a speech-weighted composite noise. Given that all of the subjects had nearly symmetrical hearing losses and reasonably similar electroacoustic values for their right and left hearing aids, the data are shown for the left

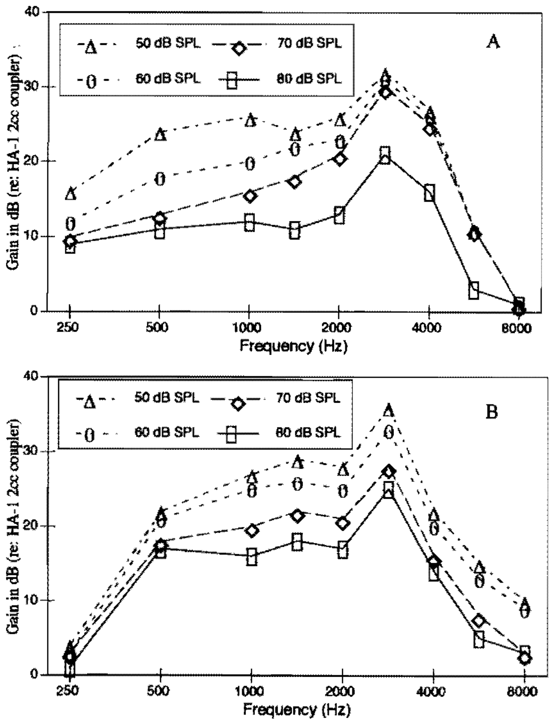


Figure 4 Mean HA-1 2-cc coupler frequency/gain responses for the MF(A) and BT2-E(B) hearing aids at 50–80 dB for the 10 subjects preferring the MF hearing aid set.

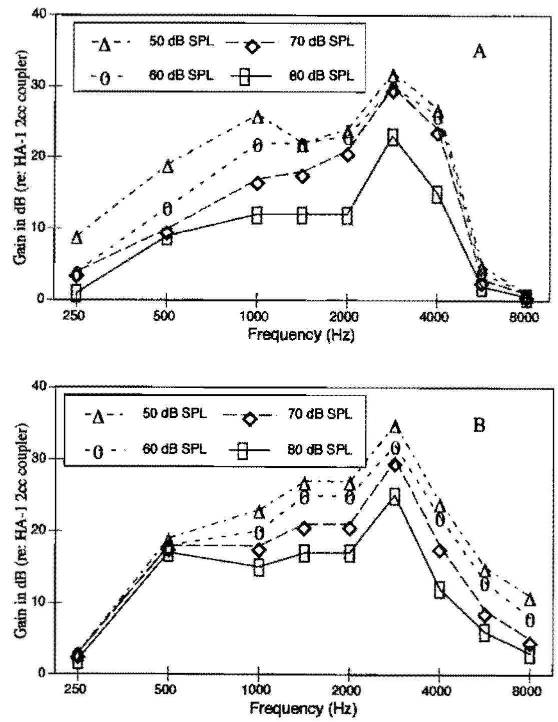


Figure 6 Mean HA-1 2-cc coupler frequency/gain responses for the MF(A) and BT2-E(B) hearing aids at 50-80 dB for the three subjects who stated no preference between the MF and BT2-E hearing aids.

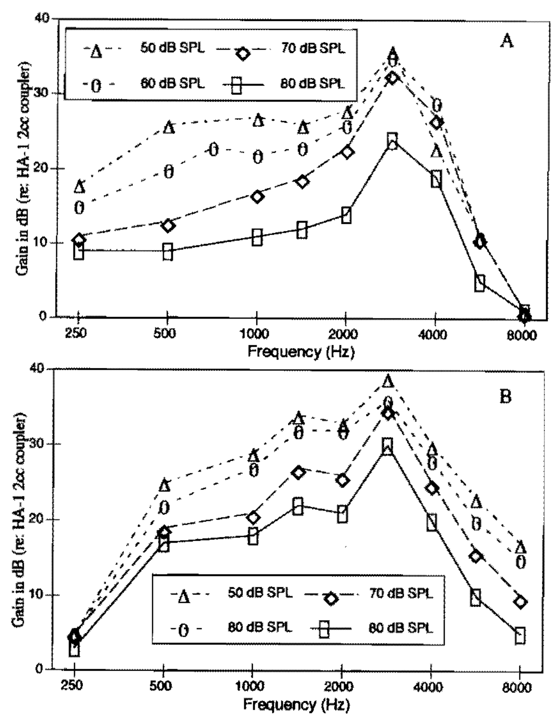


Figure 5 Mean HA-1 2-cc coupler frequency/gain responses for the MF(A) and BT2-E(B) hearing aids at 50–80 dB for the 12 subjects preferring the BT2-E hearing aid set.

ear only. Figure 4 represents the average coupler gain for the MF (A) and BT2-E (B) hearing aids for the 10 subjects preferring the MF. Figure 5 represents the average coupler gain for the MF (A) and BT2-E (B) hearing aids for the 12 subjects preferring the BT2-E. Figure 6 represents the average coupler gain for the MF (A) and BT2-E (B) hearing aids for the three subjects who stated that they liked the MF and BT2-E equally well. To obtain these values for the MF, the mean hearing loss for the left ear of the subjects in the given preference groups was used to adjust the LF-HTL, HF-HTL (G), and HF-HTL(P) potentiometers. To program the BT2-E, these same values were entered into the audiogram menu of the P^3. In addition, the average decibel levels for the 12 subjects for very soft (#2) and loud (#4) of the LGOB were entered into the LGOB menu of the P^3. These values (audiogram and LGOB) were used to program the BT2-E using the Audio + LGOB algorithm.

Figures 4 to 6 clearly illustrate the nonlinear processing in the low-frequency channel of the MF for inputs of 50 to 80 dB SPL versus the more linear low-frequency processing of the BT2-E. For input levels of 50 to 70 dB SPL, the

Table 5 Difference between Initial and Final Adjustments of LF-HTL, HF-HTL(G), and HF-HTL(P) Potentiometers of the MF Hearing Aid by Preference Group

	Right			*Left*		
Group Subject	*LF-HTL*	*HF-HTL(G)*	*HF-HTL(P)*	*LF-HTL*	*HF-HTL(G)*	*HF-HTL(P)*
MF						
7	0	–5	–5	0	–5	–5
12	0	–5	–5	0	–5	–5
13	+5	+5	+5	+5	+5	+5
15	0	0	0	0	0	0
16	+5	+5	+5	+5	+5	+5
19	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	–5	–5	–5	–5	–5	–5
25	0	0	0	0	0	0
BT2-E						
1	–5	–5	–15	–5	–5	–15
2	–15	–15	–15	–15	–15	–15
3	0	–10	–10	0	0	0
4	0	–5	–5	0	–5	–5
5	0	0	0	0	0	0
6	0	0	0	0	0	0
8	0	–10	–10	0	–10	–10
9	–15	–15	–15	–15	–20	–20
10	0	–5	–5	0	–5	–5
11	0	–25	–20	0	–20	–15
17	0	0	0	0	0	0
20	–5	–5	–5	–5	–5	–5
No preference						
14	0	+5	0	0	+5	0
18	+5	0	0	0	0	0
21	0	0	0	0	0	0

+ = increase potentiometer setting for the final fit re: initial setting; – = decrease potentiometer setting for the final fit re: initial setting.

MF shows what has been called a BILL-type function (base increase at low levels; Killion et al, 1990). These figures also illustrate the linear processing of the MF in high-frequency channel for inputs of 50 to 70 dB SPL, followed by a significant decrease in gain as the input is increased to 80 dB SPL, where saturation was probably reached. In contrast, the BT2-E shows a more systematic, nonlinear decrease in gain with input increasing from 50 to 80 dB SPL at and above 1000 Hz. To some extent, the BT2-E shows a TILL-type function (Killion et al, 1990).

Finally, an examination of the adjustments made from the original fittings at the 1-week follow-up also revealed a trend by preference grouping. Tables 5 (MF) and 6 (BT2-E) show the individual gain adjustments for the subjects' left and right ears at the 1-week follow-up for each hearing aid set as a function of preference grouping. Allowable adjustments were made using a 5-dB stepsize in the MF and a 2-dB stepsize in the BT2-E. As a general rule, the subjects who preferred the MF (who tended to have more severe hearing losses) required no adjustment (N = 5) or only one stepsize adjustment either way (± 5 dB; N = 5) to their MF fit. However, when greater than one stepsize change (> 2 dB) was made in the BT2-E, they were always in the direction of increased gain at the follow-up (N = 5). In contrast, for the 12 subjects who preferred the BT2-E (and who tended to have less severe hearing losses), 10 required either no or minimal adjustments of the BT2-E, whereas 6 subjects required equal to or greater than 10-dB decreases in gain with their MF fitting. For reasons not clear, subject #21, who had no preference, required large increases in gain for the BT2-E only.

CONCLUSIONS AND DISCUSSION

In conclusion, with the subject population and procedures used, the major findings of this study were as follows. First, both the MF and BT2-E were perceived as being significantly better than the subjects' own primarily single-channel linear hearing aids on the APHAB questionnaire, but not as different from each other. Second, the MF provided significantly better speech recognition performance than did the BT2-E at input levels of 50 and 65 dB SPL, but the BT2-E provided better speech recognition at an 80 dB SPL input level. Third, the manufacturers' algorithms and fitting procedures in place at the time of the study tended to result in the BT2-E being underfit for more severe hearing losses and the MF being overfit for less severe hearing losses. Finally, subjects with more severe hearing losses and poorer speech recognition tended to prefer the MF to the BT2-E, while those with less severe hearing losses and better speech recognition tended to prefer the BT2-E.

It should be noted that an advantage of the BT2-E is that, as a digitally programmable hearing aid, it is more flexible than the analog-based MF, which has only a fixed processing approach. It conceivably would be possible to program the BT2-E to produce signal processing that was more similar to the MF. However, given that the BT2-E has a 85 dB SPL front-end compression limiter that is not found in the MF and, given differences in time constants, there likely would remain some differences in performance.

Table 6 Difference between Initial and Final Adjustments of the L80, L50, H80, and H50 Settings for the BT2-E Hearing Aid by Preference Group

	Right				*Left*			
Group Subject	*L80*	*L50*	*H80*	*H50*	*L80*	*L50*	*H80*	*H50*
MF								
7	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	+4	0	0	−2
15	0	0	0	0	0	0	0	0
16	0	0	0	0	−2	−2	−2	−2
19	+2	+2	+8	+8	+2	+2	+8	+8
22	+2	+2	+4	+4	+2	+2	+4	+4
23	+4	+2	+2	+2	+2	0	0	0
24	−2	−2	0	−2	−2	0	0	0
25	0	0	0	+2	+4	+4	+2	+4
BT2–E								
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	−2	−2	−4	−2	−2	−2	−2	−2
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	+6	+6	+6	+6	+6	+6	+6	+6
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
17	+4	+4	+4	+4	+4	+4	+4	+4
20	−2	−2	−2	−2	−2	−2	−2	−2
No preference								
14	0	0	0	0	0	0	0	0
18	+6	+6	+4	+4	0	0	−4	−4
21	+8	+8	+10	+10	+10	+10	+12	+12

+ = increase gain; − = decrease gain; L80 = gain for low-frequency channel with 80 dB input; L50 = gain for low–frequency channel with 50 dB input; H80 = gain for high-frequency channel with 80 dB input; H50 = gain for high-frequency channel with 50 dB input.

It seems that the performance differences seen on the SPIN can be logically linked to effects of differences in signal processing between the hearing aid sets. For example, there are two reasonable hypotheses that can be made regarding the better SPIN performance shown with the MF at the lower input levels (a finding consistent with the comments by many subjects that the MF provided clearer speech). First, as seen in Figures 4 to 6, the MF generally provided greater gain in the lowest frequencies at the lower input levels than did the BT2-E (a finding consistent with the subjects' judgments of greater loudness for the MF, since low frequencies heavily contribute to perceived loudness). For example, in Figure 4A, the average gain provided by the MF at 250 and 500 Hz is approximately 18 and 27 dB, whereas, for the BT2-E (B), the gain is approximately 5 and 24 dB, respectively, at 250 and 500 Hz. Similar kinds of differences in the gain provided in the low-frequency channel are seen in Figure 5 (16 and 22 dB at 250 and 500 Hz for the MF; 2 and 20 dB at 250 and 500 Hz for the BT2-E) and Figure 6 (9 and 19 dB at 250 and 500 Hz for the MF; 2 and 19 dB at 250 and 500 Hz for the BT2-E). When the analysis of the SPIN was done for the LP-items and HP-items separately, there were no significant differences between the hearing aid sets on the LP-items (which are loosely equivalent to monosyllabic word list scores). In contrast, a significant difference was seen in the HP-item scores at the lowest input levels. Performance on the HP-items, with their contextual cues, would be facilitated by whole sentence recognition rather than just final word recognition. Thus, the greater low-frequency amplification provided at low-level inputs by the MF may have enhanced audibility of the cues from the lower frequency spectrum of the speech. Interestingly, Kuk and Pape (1992) reported that, when judging the clarity of speech, a greater percentage of subjects preferred greater high-frequency gain for consonant recognition but greater low-frequency gain for connected discourse.

A second hypothesis is that the linear processing in the high-frequency channel of the MF may have provided "cleaner" amplification of the important high-frequency consonants than did the WDRC programmed into the high-frequency channel of the BT2-E because compression may introduce distortion into the processed speech waveform. Despite the fact that the BT2-E appears to have provided somewhat greater high-frequency amplification, on average around 3000 Hz, than did the MF (see Figs. 4-6), static frequency response functions do not illustrate temporal, intersyllabic differences between linear and compression amplification. Some authors have suggested that compression amplification may reduce important temporal cues or disrupt the relative intensity relationships among phonemes, proving detrimental to speech recognition (e.g., Plomp, 1988). Further evaluation is needed to determine the validity of these hypotheses.

The SPIN score advantage for the BT2-E at the 80 dB SPL input can also be hypothesized to result from differences in the signal processing approaches. As illustrated in Figures 4 to 6, there is a significant decrease in gain in the high-frequency channel provided by the MF at an input level of 80 dB SPL, while the decrease in the BT2-E is less severe. For example, in Figure 4, the average gain at 2000 and 3000 Hz at an input of 80 dB SPL for the MF is approximately 12 and 19 dB, respectively. On the other hand, the average gain at these two frequencies for the BT2-E is approximately 18 and 25 dB. Similar kinds of differences in the gain provided in the high-frequency channel are seen in Figures 5 (12 and 22 dB at 2000 and 3000 Hz for the MF; 20 and 28 dB at 2000 and 3000 Hz for the BT2-E) and 6 (10 and 20 dB at 2000 and 3000 Hz for the MF; 17 and 23 dB at 2000 and 3000 Hz for the BT2-E). The superior performance of the BT2-E at the 80 dB SPL input level may be due to reaching the output compression limiting threshold at this high-level input for the MF, producing distortion products as well as the substantial decrease in gain. In contrast, the combination of the input compressor and the WDRC of the high-frequency channel of the BT2-E likely prevented saturation from being reached with the high-level input.

The subjects who preferred the MF tended to have more severe hearing losses and poorer speech recognition abilities than those who selected the BT2-E. Given that the MF produced significantly better performance on the SPIN than did the BT2-E at the lower input levels, it is logical to assume that their preference was driven by their greater need for better speech recognition, despite the fact that these subjects also typically showed more limited dynamic range and steeper loudness growth functions. That is, their preference may have been based on their communication needs (processing that produced clearer speech) rather than listening comfort (processing that produced more accurate control of loudness). The one exception, the subject with more severe hearing loss who chose the BT2-E despite substantially better SPIN scores with the MF, had severe loudness discomfort problems (as evidenced by his subjective complaints and limited dynamic range values), and therefore may have been willing to sacrifice some speech understanding for the sake of comfort.

Subjects who selected the BT2-E or had no preference tended to have less severe hearing losses and to have good speech recognition scores with either hearing aid set. Thus, speech clarity may have been a less important criterion in determining their preferred hearing aid set, leaving them to focus more on factors such as loudness comfort and perceived sound quality. Consistent with the subjects' comments shown in Table 2, the BT2-E with its WDRC in the high-frequency channel may well have produced high-frequency sound that was perceived as less tinny or sharp than the linear high-frequency processing of the MF, and better maintained amplified sounds within the subjects' comfort range. In addition, the BT2-E provided greater low-frequency amplification at higher input levels, and it is known that low-frequency energy is often preferred when patients are judging sound quality (e.g., Punch and Beck, 1980; Kuk and Pape, 1993; Stelmachowicz et al, 1994), even if it results in poorer recognition of speech.

Because there appeared to be a pattern to the adjustments at the follow-up session, the results of this study suggest that the manufacturers of the MF and BT2-E might consider changing the algorithms for programming the parameters of these two hearing aids based upon the degree of hearing loss. Specifically, the results of the study suggest that Oticon might consider reducing the gain initially prescribed for patients with milder hearing loss, while ReSound might consider changing their algorithm so that greater gain is initially provided for more severe hearing losses. In fact, since the advent of data collection for this study, Oticon has released to the market three versions of the MF, intended for mild, moderate, and severe losses (instead of the original two versions, which were intended for mild-to-moderate and severe hearing losses). The algorithm used by ReSound has also been modified since this study was initiated, but it is not known whether or not it supplies greater gain for more severe hearing losses. In addition, ReSound recently introduced the BTP behind-the-ear hearing aid for more severe hearing losses.

From the authors' perspective, one of the most important findings in this study was that both hearing aids were perceived by a majority of the subjects as providing significantly greater benefit than their current hearing aids. Because the subjects were not provided any information about hearing aid performance, were not informed about how they would benefit from the hearing aids, and were instructed that they might find the new hearing aids better, worse, or the same as their current hearing aids, the preferences seen in this study likely were not due to the subjects' perceptions that new technology was always better or to a desire to "please the experimenters." At a time when dispensers are being asked by third-party providers to show evidence that the more advanced and newer technology is "superior" to conventional technology, the current results support statements indicating the distinct and quantifiable benefits in fitting advanced technology hearing aids.

Acknowledgments. Appreciation is extended to Jacqueline Wylan, who assisted in data collection and reduction. The authors also acknowledge the insightful comments and suggestions of two anonymous reviewers as well as Curt Williams from Oticon, Inc. and Chas Pavlovic from ReSound, Corp.

Portions of this manuscript were presented as a poster session at the annual meeting of the American Academy of Audiology, April 1996, Salt Lake City, UT.

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