Publications   Division of Adult Audiology

1998

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Comparing the Performance of the Widex SENSO Digital Hearing Aid with Analog Hearing Aids

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Abstract

Differences in performance were evaluated between the Widex SENSO and several analog hearing aids currently worn by 50 hearing-impaired subjects. Subjects were initially fit with the SENSO using the manufacturer's recommended procedure. After wearing the hearing aids for 1 week, the adjustable parameters were finetuned based on subjective comments. Differences in performance between the SENSO and the subjects' current hearing aids were assessed using the Speech Perception in Noise administered at overall levels of 50, 65, and 80 dB SPL; the Hearing in Noise Test in which the background noise was presented at 50, 65, and 80 dBA; the Abbreviated Profile of Hearing Aid Benefit; and two questionnaires relating to overall preference between the SENSO and the subjects' current hearing aids.

Key Words: Abbreviated Profile of Hearing Aid Benefit, Hearing in Noise Test, ReSound, SENSO, Speech Perception in Noise, Widex

Abbreviations: APHAB = Abbreviated Profile of Hearing Aid Benefit, AV = aversiveness to sounds, BN = background noise, BTE = behind-the-ear, CIC = completely-in-the-canal, DSP = digital signal processing, EC = ease of communication, HP = high predictability, I/O = input/output, ITE = in the ear, LP = low predictability, RV = reverberation, S/N = signal-to-noise ratio, WDRC = wide dynamic range compression

Recently, digital signal processing (DSP) was introduced to the hearing health care community for ear-level hearing aids. DSP technology, in comparison to analog signal processing, reportedly may provide improved (a) recognition of speech in noise, (b) control of acoustic feedback, (c) compensation for recruitment, and (d) sound quality (Widex, 1996).

Recently, Widex introduced the Senso hearing aid, available in in-the-ear (ITE), behind-the-ear (BTE), and completely-in-the-canal (CIC) models. The processor of the Senso is a three-

band system where the input signal is divided into three independent frequency bands. The hearing aid can be programmed in situ by use of a complex tone for each of the three bands to determine the appropriate gain and output in each band. The compression characteristics of the Senso are highlighted by (1) a slow-acting, adaptive release time that is fast for signals of short duration and up to 30 seconds for signals whose intensity is fairly stable over time, (2) static compression ratios varying from 1:1 to 3:1 depending upon the magnitude of the residual auditory dynamic range, and (3) a compression threshold as low as 20 dB SPL.

Up to this point, independent research has not been reported in the professional literature evaluating the performance of DSP in comparison to analog hearing aids. This type of information is critical so that hearing health care professionals can accumulate information in which to make informed decisions concerning which method of signal processing may provide

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significantly better performance. This information can also be invaluable to manufacturers as they refine DSP technology to provide better performance than is currently available.

The primary objectives of the present study were to determine if:

1. Significant differences were present in the performance on the low predictability (LP), high predictability (HP), or total score of the Speech Perception in Noise (SPIN) test presented at input levels of 50, 65, and 80 dB SPL between the Senso and the subjects' current analog hearing aids;

2. Significant differences were present in performance on the Hearing in Noise Test (HINT) test when the noise level was fixed at 50, 65, and 80 dB SPL between the Senso and the subjects' current hearing aids;

3. Significant differences were present in the mean benefit scores for the four subscales of the Abbreviated Profile of Hearing Aid Benefit (APHAB) between the Senso and the subjects' current hearing aids;

4. Significant subjective preferences and overall benefit were present between the Senso and the subjects' current hearing aids by answering a 24-item questionnaire after using the Senso hearing aids for 30 days; and

5. Subjects found the lack of a volume control on the Senso an appealing feature.

PROCEDURES

Subjects

Fifty adults with mild to moderate severe bilateral symmetrical sensorineural hearing loss (ANSI, 1989) with no greater than a 15-dB difference in interaural thresholds at 250 to 4000 Hz were evaluated at two sites (25 subjects at Washington University School of Medicine in St. Louis, MO [Site I]; 25 subjects at Mayo Clinic in Rochester, MN [Site II]). The magnitude of hearing loss was within the recommended fitting range for the ITE (CX) and BTE (C8) hearing aids. For the CX, the hearing loss can be no greater than 75 dB HL at 250 Hz to 85 dB HL at 4000 Hz. For the C8, the hearing loss can be no greater than 90 dB HL at 250 Hz to 105 dB HL at 4000 Hz. Figure 1 reports the mean audiogram along with one standard deviation for Sites I (upper graph) and II (lower graph). Normal middle ear function was assessed via tympanometry using a 220-Hz probe tone.
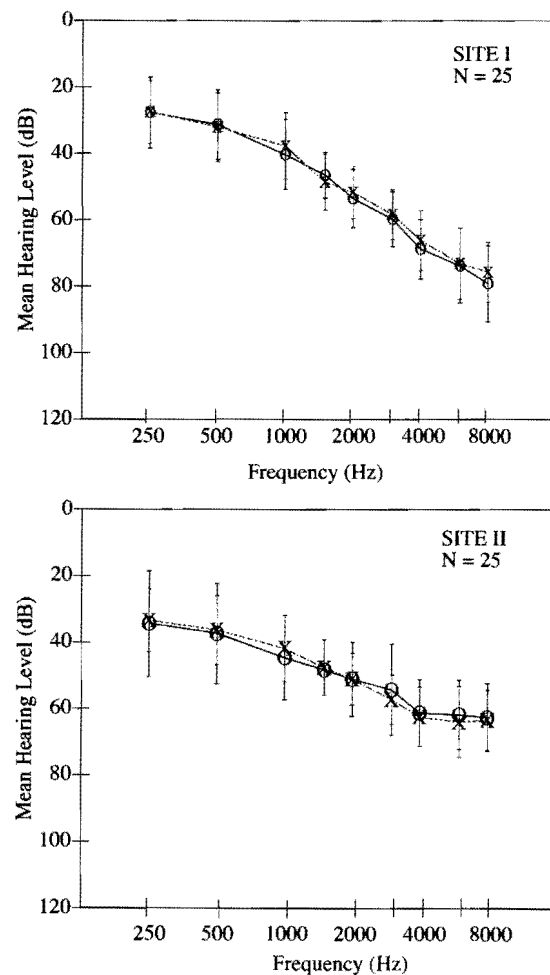
Figure 1 Mean hearing thresholds for Sites I (upper) and II (lower). Also provided are error bars reporting one standard deviation.

All subjects had prior experience with binaural amplification for at least 6 months and expressed satisfaction with their current hearing aids. At Site I, the average months of experience was 28.8 months (SD = 14.7 months; range = 9–63 months). At Site II, the mean experience was 30.6 months (SD = 12.4 months; range = 14–51 months). Appendices A through C provide information on the signal processing of the subjects' current hearing aids. As can be seen in Appendices A through C, the majority of fittings were either two-band low kneepoint (2B LKP) or two-band programmable kneepoint (2B PKP) (20/25 at Site I; 19/25 at Site II) hearing aids. The remaining hearing aids were either a dual-microphone BTE (using the omnidirectional position) with output limiting (N = 6 at Site II), one-band low kneepoint (1B LKP) (N = 3 at

Site I), or one-band high kneepoint (1B HKP) (N = 2 at Site I) fittings. Thus, 42 of the 50 subjects had been fit with hearing aids in which the signal processing was nonlinear for soft to loud input levels. It is apparent from Appendices A through C that all of the subjects were experienced users of the more advanced hearing aids currently available.

If the subject's current fitting was an ITE hearing aid (N = 15 at Site I and 10 at Site II), then the subject was fit with the ITE (CX) Senso. On the other hand, if the subject's current fitting was a BTE hearing aid (N = 10 at Site I and 15 at Site II), then the subject was fit with the BTE (C8) Senso. All of the fittings of the subjects' current hearing aids were accomplished by the authors and were judged appropriate for the magnitude and configuration of the hearing loss.

When recruiting subjects for the present study, the subjects were informed that the purpose of the present study was to evaluate the performance of a new hearing aid. Subjects were not informed about the signal processing or any other aspect of the experimental hearing aid. Subjects were not blinded as to which hearing aid condition was being evaluated. It is important to mention that the vast majority of subjects used in the present study were recruited from a larger subject-research pool and were involved in a number of projects at both sites. In many of those studies, the subjects did not demonstrate or report objective or subjective advantages for the experimental hearing aid condition. Thus, the experimenters were comfortable that the subjects used in this study were capable of providing objective and realistic responses to the objective and subjective measures in the current study. Finally, to compensate the subjects for their efforts, subjects were offered the option to purchase the experimental hearing aids at a significantly reduced cost at the conclusion of the study.

Fitting the SENSO Hearing Aids

The Senso hearing aids were fit using the manufacturer's recommended protocol. Briefly, the hearing aids were coupled to the LP2 portable programmer (software version 3.0) and placed in the ear canal. The controls on the LP2 were adjusted to the "Tone (Sensogram)" mode. Using this mode, thresholds was determined in situ in the low, mid, and high bands using the modulated tone signals (duration of approximately 1.5 seconds) generated by the LP2. The initial signal was presented at 10 dB above the predicted threshold (based upon the audiometric results obtained earlier). If there was a response, the signal was decreased in 10-dB steps until there was no response. Then the signal was increased and decreased in 5-dB steps and threshold was accepted as the lowest level where the subject correctly responded 50 percent of the time.

After threshold was determined in each of the three frequency bands, the controls of the LP2 were changed to perform the "Feedback Test" using the manufacturer's recommended protocol. The Feedback Test is an automatic test consisting of two segments. The first segment determines whether the gain calculated for the three bands based upon the results of the Sensogram can be achieved for the magnitude of hearing loss in combination with the shell or earmold used for the fitting. If the required gain can be achieved, then zeros appear in each of the windows of the three bands. If the calculated gain cannot be achieved, then a negative number suggesting the reduction of gain relative to the calculated gain appears in any or all windows. The second segment of the feedback test automatically limits the gain to prevent feedback in each of the three frequency bands of the hearing aid. For this study, if the results of the feedback test were greater than −10 in any band, then the shell or earmold was returned to the manufacturer for a remake.

At the completion of the initial fit, the experimenter and subject conversed at average conversational levels to determine if finetuning of the initial settings was necessary. Following the manufacturer's recommended protocol, the gain (i.e., HTL setting) in the mid-band was increased by 5 dB. If the subject stated this was "better," then the gain was increased in 5-dB steps until the subject stated that the sound quality was "worse." At this point, the gain in the mid-band was reduced in 5-dB steps to obtain the last clearly preferred level. If the answer to the initial question was "no, it is not better," then the gain was reduced 5 dB in the mid-band until the subject stated that it was "too weak." At this point, the gain was increased in 5-dB steps until the subject indicated that it was the preferred level. At this point, the mid-band was considered finetuned. This same procedure was followed for the high-band, where the subject was asked if the adjustment in gain changed the "clarity" of the speech, and in the low-band, where the subject was asked if the adjustment created a change in the "listening comfort" of the speech. After each adjustment, the feedback test was repeated.

To finetune for "loud-sounds," a speech-weighted noise at 85 dB SPL generated from a Frye 6500 real-ear analyzer to a loudspeaker 18 inches from the subject's head was presented to the subject. If the subject reported that the signal was "too loud or uncomfortable," the low and mid-band UCL windows of the LP2 were reduced in 5-dB steps until the subject reported that the amplified sound was no longer uncomfortable.

The subject wore the hearing aids for 1 week and they were again finetuned in the following manner. If the subject reported that the hearing aids "whistled," then the feedback levels in the mid- and/or high-bands were increased in 2- to 4-dB steps to eliminate the feedback. If the subject reported that the hearing aids were "noisy," then the gain in the mid- and/or high-bands were reduced slightly. If the subject reported that the hearing aids were "too soft," then the gain in the low-and/or mid-band was increased 5 to 10 dB. If the subject reported that the gain was "too great," then the gain in the low-and/or mid-bands was reduced 5 to 10 dB. If the subject reported that "their voice sounds too hollow," then the gain in the low-band was reduced 5 to 10 dB. If the subject reported that the hearing aid "distorts," then the band with the greatest amount of gain was reduced 5 to 10 dB.

Revised Speech Perception in Noise (R-SPIN)

After the experimental hearing aids were adjusted to the subjects' preference, the revised Speech Perception in Noise (R-SPIN) was administered. The eight lists of the R-SPIN stimuli were recorded on a compact disc, distributed by Cosmos Distributing Inc.[1] Site II used the tape version of the R-SPIN. Each list contains 50 sentences for which the subject's task is to write down the final word of each sentence. One half of the sentences are LP items, which supply no contextual cues to identify the final word, and the other half are HP items, which have contextual cues. The R-SPIN has been described in detail (Kalikow et al, 1977; Bilger et al, 1984).

For this study, the sentences of the R-SPIN were presented at overall levels of 50, 65, and 80 dBA, while the level of the 12-talker babble

was presented 8 dB softer than each presentation level. This maintained a +8 dB signal-to-noise ratio (S/N) across the presentation levels.

R-SPIN measures were obtained for the LP-item, HP-item, and total R-SPIN scores. The range for the LP-item and HP-item scores can be from 0 to 25, in steps of 1. To obtain the total R-SPIN score, the examiner used the nomograph supplied with the R-SPIN recordings. Using this nomograph, the investigator found the column corresponding to the LP-item score and the row corresponding to the HP-item score. Where the row and column intersect was the resulting total R-SPIN percent hearing for speech score. This nomograph is suggested as the method to calculate the total R-SPIN score after the LP- and HP-item scores were obtained.

To ensure that the presentation levels were correct, a 1-inch microphone connected to a Quest 215 sound level meter was placed at ear level 1 meter from a loudspeaker at 0° azimuth with the head absent. The attenuator and VU meter of the audiometer (Grason-Stadler 16) was adjusted for Channel 1 until the required three overall levels were obtained using the 1000-Hz calibration tone. The same procedure was followed on Channel 2 to calibrate the input levels of the multitalker babble. The R-SPIN stimuli were presented to the audiometer using a compact disc recorder. LP-item, HP-item, and total R-SPIN scores were obtained for the three presentation levels (50, 65, and 80 dB) for the two aided conditions (Senso and current aids). LP-item, HP-item, and total R-SPIN scores for the subjects' current aids were measured when the subject first entered the study.

Hearing in Noise Test (HINT)

The HINT (Nilsson et al, 1994; Soli and Nilsson, 1994) consists of 250 sentences (25 lists of 10 sentences per list) read by a male speaker. The sentences are of approximately equal length (six to eight syllables) and difficulty (first-grade reading level) and have been digitally recorded for standardized presentation. The HINT estimates the S/N at which the sentences, embedded in noise, can be repeated correctly 50 percent of the time. This type of measure is useful because it enables accurate, reliable estimation of speech recognition in noise for context-rich speech materials.

In this study, the sentences were presented at 0° azimuth, and the noise, which is temporally and spectrally matched to the sentences, was presented at 180° azimuth. The subject was seated

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[1]Cosmos Distributing Inc., 508-428 Portage Ave., Winnipeg, MB, Canada R3C 0E2.

Table 1   Questionnaire Use to Determine Preference between the Subjects' Current Hearing Aids and the Senso (Experimental Hearing Aids)

Speech Quality	Current Hearing Aids	Experimental Hearing Aids	Both	Neither
Speech was more:				
Distinct				
Pleasant				
Natural				
Comfortably loud				
Uncomfortably loud				
Performance was better with a close friend one on one				
Performance was better with a stranger one on one				
Performance was better listening to a speaker across the room				
Performance was better listening to TV with no one else talking				
Performance was better listening to TV with one or more people talking in the background				
Performance was less frustrating				
Performance was better listening at a meeting with one speaker				
Performance was better listening at a meeting with several speakers				
Performance was better listening at a family gathering				
Performance was better listening to the radio in the car				
Performance was better listening to a passenger in the car				
Performance was better listening in an "elegant" restaurant				
Performance was better listening in a family restaurant				
Performance was better listening to sounds at a distance				
Performance was better listening in a house of worship				
Performance was better listening in a movie theater				
Performance was better listening to recorded music				
Quiet sounds were more audible				
My performance was best with				

approximately 1.1 meters equidistant from two loudspeakers in a 8'4" × 9' (Site I) or 10' × 8' (Site II) double-walled sound suite. Neither sound suite was anechoic and reverberation time was not measured. However, Nielson and Ludvigsen (1978), Studebaker et al (1980), and Madison and Hawkins (1983) report reverberation times of between 0.1 to 0.6 seconds in audiometric sound suites of similar size. The sentences and competing noise were presented through a Grason-Stadler 16 (Site I) or Grason-Stadler 10 (Site II) clinical audiometers via a Sony DTC-690 digital audiotape (DAT) recorder.

The administration of the HINT requires two lists to be presented (20 sentences each) for each experimental condition. The first sentence was presented 10 dB below the attenuator setting necessary for the noise to be presented at 50, 65, and 80 dBA. The first sentence was repeated, increasing the level of presentation by 4 dB, until repeated correctly by the subject. Subsequently, the intensity level was decreased by 4 dB and the second sentence presented. Stimulus level was raised (incorrect response) or lowered (correct response) by 4 dB after the subject's response to the second, third, and fourth sentences. The step size was reduced to 2 dB after the fourth sentence, and a simple up-down stepping rule was continued for the remaining 15 sentences. The calculation of the S/N necessary for 50-percent sentence recognition was based on averaging the presentation level of sentences 5 through 20, plus the calculated intensity for the twenty-first presentation. HINT thresholds were obtained for the three levels of background noise (50, 65, and 80 dBA) and the
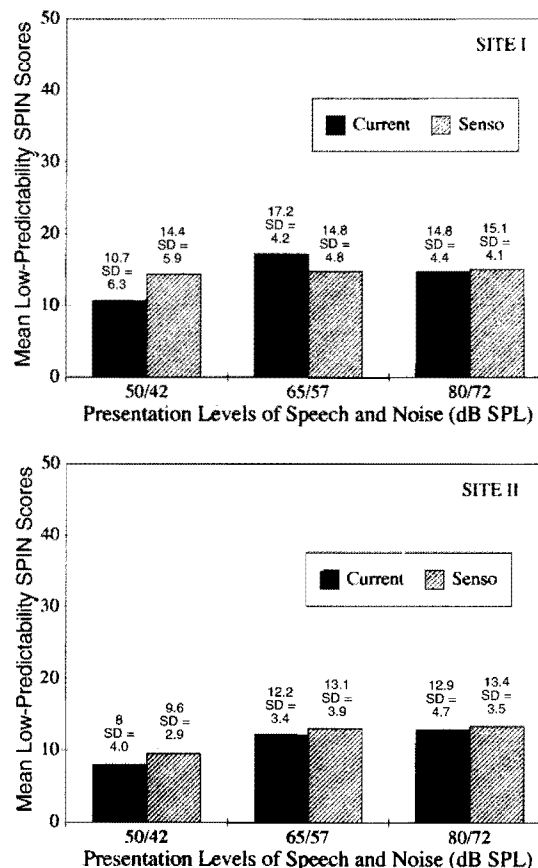
two hearing aid conditions (Senso and current hearing aids). HINT thresholds for the subjects' current aids were measured when the subject first entered the study.

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 (A–G, 0–100%). The subject responds to each question for unaided and aided problem scores. Responses to the unaided segment were obtained prior to the fitting of the Senso hearing aids, while responses to the aided segment were obtained at the end of 4 weeks. APHAB scores were already obtained on the current aids at the time of the original fit. Hearing aid "benefit" (in percent) is defined as the difference between the unaided and aided problem scores. The APHAB is scored as four subscales, which include ease of communication (EC), reverberation (RV), background noise (BN), and aversiveness of sounds (AV).

Additional Subjective Assessment

Subjects were asked to complete a 24-item questionnaire (Table 1) assessing their preference between the Senso and their current hearing aids after wearing the Senso hearing aids for 30 days by focusing on differences in sound quality and loudness in a variety of listening situations. The final item in the questionnaire reported the overall satisfaction between the two hearing aid systems. For each question, the subject was asked to assess if the Senso or their current hearing aids provided better performance (column 1 or 2), equivalent performance (column 3), or if neither hearing aid provided satisfactory performance (column 4). The next questionnaire asked if subjects felt that the perceived benefit provided by the Senso was (1) significantly better, (2) better, (3) equal, (4) poorer, or (5) significantly poorer than the perceived benefit of their current hearing aids after wearing the Senso for 30 days. Finally, after using the Senso hearing aids for 30 days, the subjects were asked to state how appealing the absence of a volume control on the Senso was when compared to their current hearing aids, which had volume controls.

Figure 2 Mean low-predictability SPIN scores for the Senso and current hearing aids at input levels of 50, 65, and 80 dB SPL for Sites I (upper) and II (lower). Also provided is one standard deviation.

RESULTS AND DISCUSSION

SPIN

Figures 2 to 4 report the mean and standard deviation for the LP (see Fig. 2), HP (see Fig. 3), and total R-SPIN (see Fig. 4) scores for Sites I (upper graph) and II (lower graph) for the Senso and subjects' current hearing aid at the three presentation levels. Appendix A reports the individual LP, HP, and total R-SPIN scores for the two hearing aid conditions, two sites, and three presentation levels.

For the LP items (see Fig. 2), a three-way split-plot analysis of variance (ANOVA) (aids x level x site) revealed a significant three-factor interaction (F = 6.40; df = 2, 96; p < .01). Post hoc analysis using the Tukey HSD test revealed that the mean LP item score at the overall level of 50 dBA at Site I for the Senso (14.4 items) was significantly better (p < .01) than the same score for the subjects' current hearing aids (10.7 items).
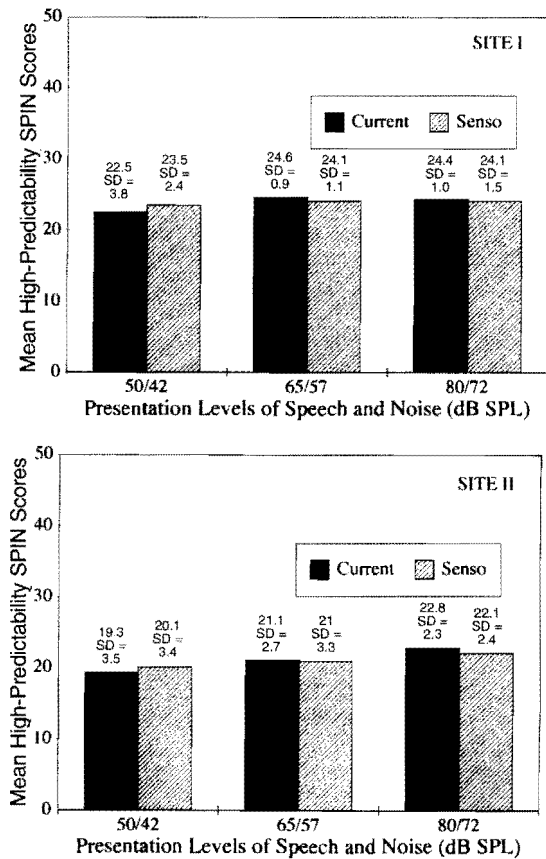
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Figure 3 Mean high-predictability SPIN scores for the Senso and current hearing aids at input levels of 50, 65, and 80 dB SPL for Sites I (upper) and II (lower). Also provided is one standard deviation.

Figure 4 Mean total SPIN scores for the Senso and current hearing aids at input levels of 50, 65, and 80 dB SPL for Sites I (upper) and II (lower). Also provided is one standard deviation.
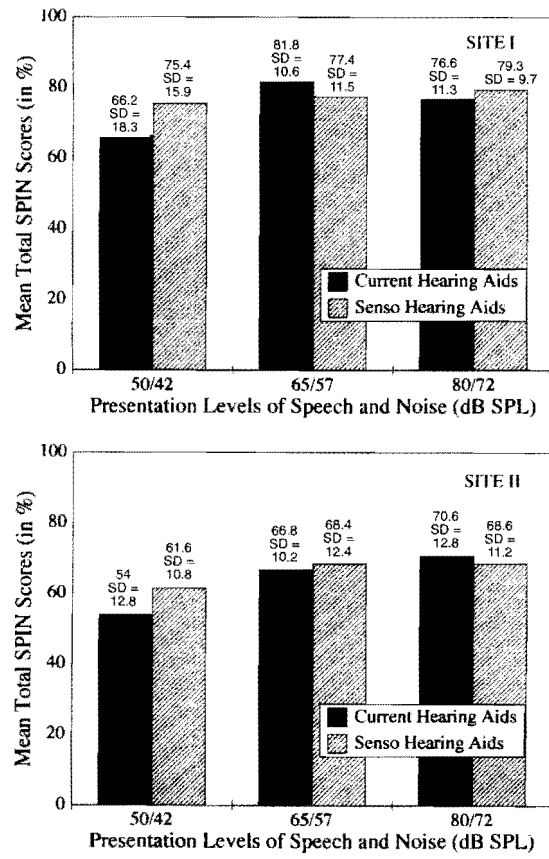
All other differences in performance between the Senso and the subjects' current hearing aids were found not to be statistically different from each other. Second, there was a significant aid effect (F= 6.52; df = 1, 48; p < .01) where the overall (i.e., across levels and sites) mean performance for the Senso (13.4 items) was significantly better than the overall mean performance of the current hearing aids (12.6 items). Third, there was a significant group effect (F = 98.44; df = 1, 48; p < .01) where the overall (i.e., across aids and levels) mean performance for Site I (14.5 items) was significantly better than the overall mean performance for Site II (11.5 items). Fourth, there was a significant level effect (F = 60.68; df = 2, 96; p < .01) where the overall (i.e., across aids and sites) mean performance for input levels of 65 dBA (14.3 items) and 80 dBA (14.0 items) were significantly better than the mean performance at 50 dBA (10.7 items). However, the mean differences in performance

between 65 and 80 dBA were not significantly different from each other.

For the HP items (see Fig. 3), a three-way ANOVA revealed no significant differences between the performance of the Senso and the subjects' current hearing aids at any of the presentation levels for either site. However, there was a significant presentation level by site interaction (F = 11.15; df = 2, 48; p < .01) where at each presentation level, the mean HP-item score for Site I (23.0, 24.4, and 24.3 items at 50, 65, and 80 dBA, respectively) was significantly better than the mean HP-item score for Site II (19.7, 21.1, and 22.5 items at 50, 65, and 80 dBA). In addition, there was a significant hearing aid by presentation level interaction (F = 8.56; df = 2, 96; p < .01). Post hoc analysis using the Tukey test revealed that the mean performance for the Senso (21.8 items) was significantly better (p < .01) than the mean performance for the current hearing aids (20.9

items) when the R-SPIN was presented at 50 dBA. Differences between the performance for the Senso and current aids at the other two presentation levels were not found to be significantly different from each other. Third, there was a significant group effect (F = 355.70; df = 1, 48; p < .01) where the overall mean performance for Site I (23.9 items) was significantly better than the mean performance for Site II (21.1 items) averaged across the experimental conditions of hearing aids and presentation level. Finally, there was a significant level effect (F = 63.71; df = 2, 96; p < .01) where the mean performance for input levels of 65 dBA (22.7 items) and 80 dBA (23.4 items) was significantly better than the mean performance at 50 dBA (21.4 items), but the mean differences in performance between 65 and 80 dBA were not significantly different from each other.

For the total percent score (see Fig. 4), a three-way split-plot ANOVA revealed a significant three-factor interaction (F = 3.40; df = 2, 96; p < .03). Post hoc analysis using the Tukey test revealed that the mean total percent score at the overall level of 50 dBA at Site I for the Senso (75.4%) was significantly better (p < .01) than the same score for the subjects' current hearing aids (66.2%). All other differences in performance between the Senso and the subjects' current hearing aids were not statistically significant from each other. Second, there was a significant group effect (F = 262.56; df = 1, 48; p < .01). Post hoc analysis using the Tukey test revealed that the mean performance for Site I (76.1%) was significantly better (p < .01) than the mean performance for Site II (65.0%) averaged across the experimental conditions of hearing aids and presentation level. In addition, there was a significant presentation level by site interaction (F = 5.83, df = 2, 48; p < .01). A post hoc analysis using the Tukey test revealed that at each presentation level the mean score for Site I (70.8%, 79.6%, and 77.9% at 50, 65, and 80 dBA, respectively) was significantly better (p < .01) than the mean score for Site II (57.8%, 67.6%, and 69.6% at 50, 65, and 80 dBA, respectively). Finally, there was a significant hearing aid by presentation level interaction (F = 14.00; df = 2, 96; p < .01). A post hoc Tukey test revealed that the overall mean performance for the Senso (72.1%) was significantly better (p < .01) than the overall mean performance for the current hearing aids (63.4%) when the R-SPIN sentences were presented at 50 dBA. Mean differences between the Senso and the subjects' current hearing aids were not found to be

significant at 65 dBA (72.9% for Senso and 74.3% for current aids) and 80 dBA (73.9% for Senso and 73.6% for current aids).

Two major findings are apparent from the results with the R-SPIN. First, performance was significantly better for the Senso than the subjects' current hearing aids when the input level was 50 dBA at Site I. However, significant differences were not present between hearing aid conditions when the input level was 65 or 80 dBA at either site. Second, the overall performance for the LP- and HP-items and total percent score of the subjects at Site I was significantly better than the overall performance for the subjects at Site II.

Figure 5 illustrates an idealized input/output (I/O) function for three different types of signal processing matched in output to a stimulus presented at average conversational level. The solid line represents the I/O function for linear signal processing where the amplification is linear for input levels to 80 dB SPL, and this is followed by a compression kneepoint at approximately 80 dB SPL where output limiting begins. The long-dashed line represents the I/O function for wide dynamic range compression (WDRC) where the amplification is linear for input levels to 40 dB SPL. This is followed by nonlinear amplification for input levels between 40 to 80 dB SPL and then output limiting for input levels above 85 dB SPL. The short-dashed line represents the I/O function for the Senso where an expansion circuit is used for input levels below 20 dB SPL. This is followed by nonlinear amplification for input levels to approximately 70 dB SPL. For input levels of 70 to 90 dB SPL, the Senso provides linear amplification. For input levels above 90 dB SPL, the Senso provides soft output limiting to limit the output and minimize distortion.

In looking at the I/O function in Figure 5, it is apparent that the Senso provides greater amplification for low input signals when compared to hearing aids with linear and WDRC signal processing. It is hypothesized that the improved performance of the Senso at the input level of 50 dBA may be related to the lower kneepoint (and therefore greater amplification) in Senso than is found with linear or WDRC signal processing. At this point, it is important to keep in mind that the actual placement of the kneepoints within the Senso is directly related to the magnitude of the feedback level measured in the three bands with the LP2 programmer. A kneepoint of 20 dB SPL is expected if 0 is obtained as the feedback value. A higher
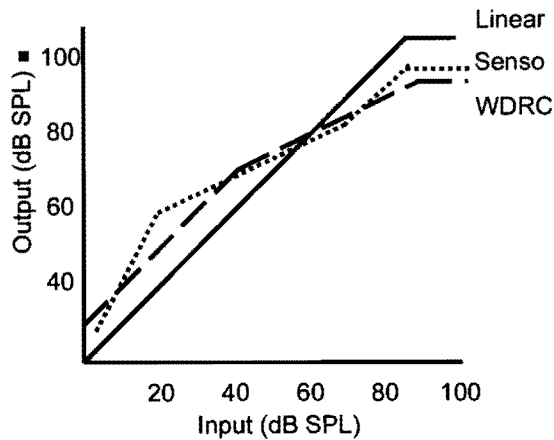
Figure 5 Idealized input-output curves for hearing aids with linear and wide dynamic range compression (WDRC) and the Senso.

kneepoint is expected with more negative feedback values. That is, the placement of the three kneepoints of the Senso will vary from one subject to the next depending upon the measured feedback level. In contrast, the kneepoint in hearing aids with linear or WDRC signal processing is constant regardless of hearing level. The impact of these differences in kneepoint placement as a function of differences in signal processing and hearing level and the resulting impact on speech recognition and sound quality need to be investigated.

In addition, it was found that the improved performance of the Senso at the input level of 50 dBA was only at Site I and that the overall performance at Site I was significantly better than at Site II. It is hypothesized that the difference in performance between Sites I and II may be related to an average difference in hearing loss between the two sites. Looking at Figure 1, the average hearing loss at Site I was better by 6 dB to 4 dB at 250 to 1000 Hz, respectively. This improved hearing at 250 to 1000 Hz at Site I, in combination with the lower kneepoint of the Senso, may have allowed more of the speech signal to be audible than was possible for the subjects at Site II. These differences in average hearing thresholds between Sites I and II may have also been the cause of the improved performance of the subjects at Site I in the HP-item and total percent R-SPIN scores. Other reasons for the observed differences between Sites I and II may be related to (a) slight differences in soundfield calibration, (b) possible differences in the frequency response and/or bandwidth of the loudspeakers, or (c) other differences between the subjects (i.e., word recognition ability).

HINT

Figure 6 reports the mean and standard deviation of the S/N for the two hearing aids and three input intensity levels of noise for Sites I and II. Appendix B reports the individual HINT thresholds for the two hearing aid conditions, two sites, and three presentation levels. A split-plot ANOVA revealed a significant level effect (F = 19.65; df = 2, 48; p < .01) where the mean HINT threshold at 50 dBA (2.9 dB) was significantly poorer than the mean HINT threshold at 65 dBA (1.4 dB) and 80 dBA (2.3 dB). In addition, the mean HINT threshold at 80 dBA was significantly poorer than the mean HINT threshold at 65 dBA. As a general rule, both hearing aids required greater levels of the signal to maintain 50 percent recognition when the background noise was 50 and 80 dBA and reduced levels of the signal when the background noise was 65 dBA. Unlike the results with the R-SPIN, there were no significant differences in overall mean performance between the two hearing aids or sites.

APHAB

Figure 7 reports the mean APHAB benefit scores for the EC, RV, BN, and AV subscales for the two hearing aid conditions for Sites I and II. Appendix C reports the individual APHAB benefit scores for the four subscales for the two hearing aid conditions and the two sites. Separate two-way (aid × site) ANOVAs were performed for each of the four subscales. For the EC subscale, there was a significant hearing aid by site interaction (F = 4.64; df = 1, 48; p < .03). A post hoc analysis using the Tukey test revealed that the mean benefit score for the Senso (32.3%) was significantly better (p < .01) than the mean benefit score for the subjects' current hearing aid at Site II (26.2%). However, significant differences were not present for the two hearing aid conditions at Site I (36.1% vs 35.2%). In addition, there was a significant hearing aid effect (F = 6.87; df = 1, 48; p < .01) where the mean EC benefit score for the Senso (34.2%) was significantly better than the mean EC benefit score for the current hearing aids (30.9%). Finally, there was a significant site effect (F = 26.62; df = 1, 48; p < .01) where the mean EC benefit score for Site I (35.8%) was significantly better than the mean EC benefit score for Site II (29.3%).

For the RV subscale, there was a significant hearing aid by site interaction (F= 4.64; df = 1, 48; p < .03). A post hoc analysis using the Tukey
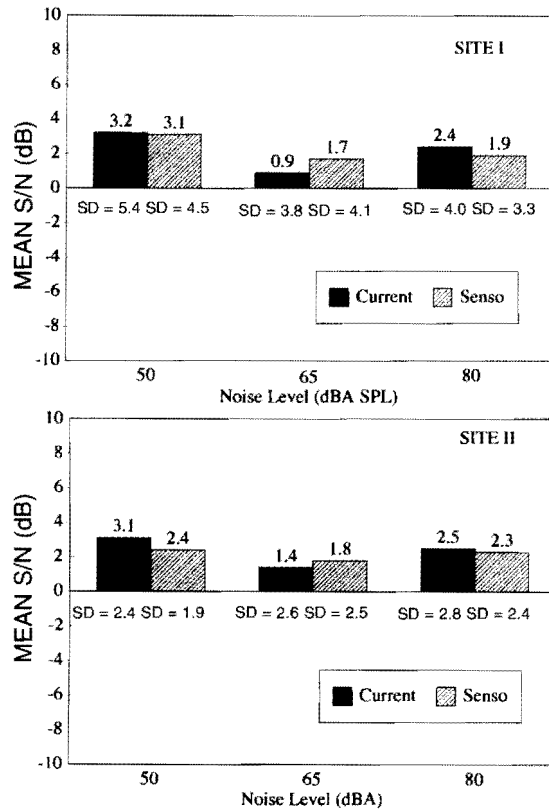
Figure 6 Mean signal-to-noise ratio (S/N) for the HINT test for the Senso and current hearing aids at input levels of 50, 65, and 80 dBA for Sites I (upper) and II (lower). Also provided is one standard deviation.
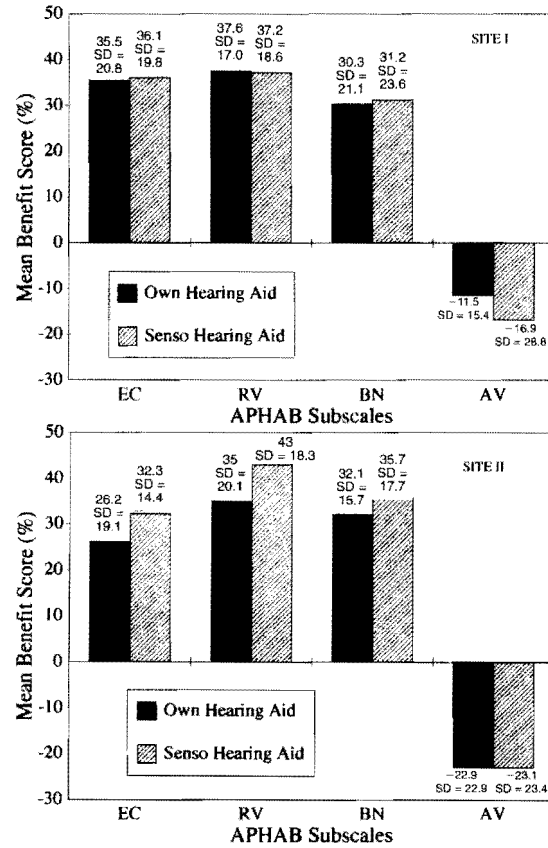
Figure 7 Mean APHAB benefit scores for the EC, RV, BN, and AV subscales for Sites I (upper) and II (lower). Also provided is one standard deviation.

test revealed that the mean benefit score for the Senso (43.0%) was significantly better (p < .01) than the mean benefit score for the subjects' current hearing aid at Site II (35.0%). However, significant differences were not present for the two hearing aid conditions at Site I (37.2% vs 37.6%). In addition, there was a significant aid effect (F = 6.87; df = 1, 48; p < .01) where the mean RV benefit score for the Senso (40.1%) was significantly better than the mean RV benefit score for the current hearing aids (36.3%). Finally, there was a significant site effect (F = 26.62; df = 1, 48; p < .01) where the mean RV benefit score for Site II (39.0%) was significantly better than the mean RV benefit score for Site I (37.4%).

For the BN and AV subscales, two-way ANOVAs reported no significant hearing aid or site effects or interactions. Cox (1997) reported that there must be at least a 5-percent difference in benefit scores for the EC, RV, and BN subscales between two hearing aid conditions in order for the results to indicate that one hearing aid is providing statistically significant

greater benefit than another hearing aid. The mean results in Figure 7 do not illustrate the required 5-percent difference in the three subscales.

Questionnaire on Preference between Hearing Aids

Tables 2 to 3 report the responses to the 24 items relating to sound quality (1–3), loudness (4–5), listening situations (6–23), and overall performance (24). Table 2 reports the responses for the subjects from Site I. Table 3 reports the responses for the subjects from Site II. Each row in Tables 2 to 3 represents the number of subjects who responded to each question.

Separate McNemar χ^2 tests (SAS, 1989) were performed on the data appearing in Tables 2 to 3. The McNemar χ^2 test is used to determine if significant differences are present between related measures on the same subject. For Site I (see Table 2), the results of the McNemar χ^2 test revealed that a significantly greater number of

Table 2   Responses to the Preference Questionnaire at Site I*

Speech Quality	Current Hearing Aids	Experimental Hearing Aids	Both	Neither	No Response
Speech was more:					
1. Distinct	2	10	11	2	0
2. Pleasant	10	7	7	1	0
3. Natural	14	5	5	1	0
4. Comfortably loud	7	8	9	1	0
5. Uncomfortably loud	4	6	1	13	1
6. Performance was better with a close friend one on one	2	7	14	2	0
7. Performance was better with a stranger one on one	3	7	12	3	0
8. Performance was better listening to a speaker across the room	5	11	8	1	0
9. Performance was better listening to TV with no one else talking	4	10	10	1	0
10. Performance was better listening to TV with one or more people talking in the background	4	10	3	6	2
11. Performance was less frustrating	6	11	4	4	0
12. Performance was better listening at a meeting with one speaker	1	8	14	2	0
13. Performance was better listening at a meeting with several speakers	5	7	7	4	2
14. Performance was better listening at a family gathering	8	11	5	1	0
15. Performance was better listening to the radio in the car	6	12	6	1	0
16. Performance was better listening to a passenger in the car	8	9	5	2	1
17. Performance was better listening in an "elegant" restaurant	4	5	10	2	4
18. Performance was better listening in a family restaurant	4	12	5	3	1
19. Performance was better listening to sounds at a distance	6	10	5	4	0
20. Performance was better listening in a house of worship	4	7	7	1	6
21. Performance was better listening in a movie theater	7	6	3	1	8
22. Performance was better listening to recorded music	4	8	9	2	2
23. Quiet sounds were more audible	5	17	3	0	0
24. My performance was best with	7	13	5	0	0
Total	130	217	168	58	27

*Each column represents the number of subjects responding to each of the four choices and the number of subjects who did not respond to that question. Each row represents the total responses of the 25 subjects.

subjects preferred the Senso to their current aids for items 1 ("more distinct"), 12 ("better listening in a meeting with one speaker"), and 24 ("overall, performance was best with...") (p < .05). Although in 19 of the remaining 21 items a greater number of subjects reported a preference for the Senso, these differences were not found to be statistically different from each other.

For Site II (see Table 3), the results of the McNemar χ^2 test revealed that a significantly greater number of subjects preferred the Senso to their current aids for items 3 to 8, 10, 13 to 15, 17 to 18, 20, and 22 (p < .01). Also, a significantly greater number of subjects preferred their current hearing aids to the Senso for item 9 ("listening to TV with no one else talking") (p < .01). All other comparisons were found not to be significantly different from each other.

The results from Figure 7 (APHAB) and Tables 2 to 3 indicate that a greater number of subjects from Site II reported a preference for the Senso to their current hearing aids than did the subjects at Site I. It is difficult to find a

Table 3   Responses to the Preference Questionnaire at Site II*

Speech Quality	Current Hearing Aids	Experimental Hearing Aids	Both	Neither	No Response
Speech was more:					
1. Distinct	0	0	24	1	0
2. Pleasant	0	1	23	1	0
3. Natural	0	23	2	0	0
4. Comfortably loud	0	24	0	1	0
5. Uncomfortably loud	1	13	10	1	0
6. Performance was better with a close friend one on one	2	15	5	3	0
7. Performance was better with a stranger one on one	0	15	2	8	0
8. Performance was better listening to a speaker across the room	0	16	8	1	0
9. Performance was better listening to TV with no one else talking	12	1	9	3	0
10. Performance was better listening to TV with one or more people talking in the background	1	23	0	1	0
11. Performance was less frustrating	11	7	7	0	0
12. Performance was better listening at a meeting with one speaker	14	5	3	3	0
13. Performance was better listening at a meeting with several speakers	0	20	4	1	0
14. Performance was better listening at a family gathering	3	17	4	1	0
15. Performance was better listening to the radio in the car	2	14	5	3	1
16. Performance was better listening to a passenger in the car	4	4	16	1	0
17. Performance was better listening in an "elegant" restaurant	0	23	1	1	0
18. Performance was better listening in a family restaurant	1	18	3	2	1
19. Performance was better listening to sounds at a distance	1	2	21	1	0
20. Performance was better listening in a house of worship	0	22	2	1	0
21. Performance was better listening in a movie theater	12	7	2	4	0
22. Performance was better listening to recorded music	2	15	4	4	0
23. Quiet sounds were more audible	14	8	2	1	0
24. My performance was best with	6	11	3	5	0
Total	86	304	160	48	2

*Each column represents the number of subjects responding to each of the four choices and the number of subjects who did not respond to that question. Each row represents the total responses of the 25 subjects.

precise reason to account for the differences in preferences between Sites I and II. However, early in the investigation, it became apparent to the investigators that subjects with a flat or gradual sloping audiometric configuration seemed to prefer the amplification provided by the Senso when compared to their current hearing aids, while subjects with sharply falling or precipitous audiometric configurations seemed to prefer the amplification provided by their current hearing aids. Table 4 reports the number of ears at Sites I and II as it relates to dif-

ference in hearing threshold at 500 Hz versus 3000 Hz. A value of 0 indicates no difference in threshold between these two frequencies (i.e., a flat configuration), where a value of 60 indicates that the hearing threshold at 3000 Hz was 60 dB poorer than the hearing threshold at 500 Hz (i.e., precipitous configuration). In looking at Table 4, it is clear that there was a greater number of audiometric configurations at Site II that were flatter or more gradually sloping than were present at Site I. Therefore, a larger number of audiometric configurations at Site I

Table 4   Differences in Threshold between 500 and 3000 Hz at Sites I and II and the Number of Ears That Fell into Each Category

Threshold Differences at 500–3000 Hz	Number of Ears	
	Site I	Site II
0	0	2
5	2	6
10	5	9
15	6	4
20	6	8
25	5	4
30	6	6
35	10	3
40	1	5
45	3	2
50	4	1
55	1	0
60	1	0

were more steeply sloping or precipitous than at Site II. Widex has become aware of this possibility and has changed the algorithms to better account for the effect of audiometric configuration in the selection of the three crossover frequencies (filter sets of F1, F2, and F3), as well as the differences in gain programmed between adjacent bands (i.e., low, mid, and high).

Additional Subjective Assessment

Table 5 reports the results from the questionnaire asking the subjects to state how they would rate the overall performance of the Senso to their current hearing aids. For Site I, 14 of 25 subjects (56%) rated the performance of the Senso as "significantly better" or "better" than the performance of their current hearing aids. Six of the 25 subjects (24%) rated the overall per-

Table 5   Summary of Responses to the Questionnaire Concerning the Rating of the Overall Performance of the Experimental Hearing Aids to the Subject's Current Hearing Aids

Site			
I	II	Combined	Response
3	5	8	Significantly better
11	11	22	Better
6	6	12	No significant difference
3	3	6	Poorer
2	0	2	Significantly poorer

formance of the Senso to be as good as the performance of their current hearing aids. Five of 25 subjects (20%) felt that the performance of the Senso was "poorer" or "significantly poorer" than the performance provided by their current hearing aids. For Site II, 16 of 25 subjects (64%) rated the performance of the Senso as "significantly better" or "better" than the performance of their current hearing aids. Six of the 25 subjects (24%) rated the overall performance of the Senso to be as good as the performance of their current hearing aids. Three of 25 subjects (12%) felt that the performance of the Senso was "poorer" than the performance provided by their current hearing aids. These results are in agreement with a study by Knebel and Bentler (1998), who reported that 100 percent of their subjects having prior experience with amplification reported a preference for the sound quality produced by the experimental hearing aids (Widex Senso and Oticon DigiFocus) in comparison to their current hearing aids. In addition, 65 percent of the subjects preferred the Senso to the DigiFocus. Reasons given for preferring the Senso included a better battery drawer that provided improved manual dexterity, presence of an on/off switch, and greater comfort in BN.

Another major finding of this study is the general lack of agreement between the Senso and the subjects' hearing aids using objective (i.e., SPIN and HINT) and subjective (i.e., APHAB and questionnaires) measures. Generally, the objective measures could not demonstrate significant differences in performance between the Senso and the subjects' current hearing aids (with the exception of the SPIN at 50 dB SPL for Site I). However, subjective measures generally indicated a preference for the Senso. The lack of agreement between objective and subjective measures was also reported in another unpublished study in the Netherlands (Ludvigsen, personal communication, 1996). In that study, differences in performance could not be demonstrated between the Senso and the subjects' current hearing aids using speech recognition tests, but there was a strong subjective preference for the Senso.

Why could these investigations not find significant differences in performance between the Senso and the subjects' current aids when measuring performance of the recognition of sentences mixed with noise, but, at the same time, many subjects reported a preference for the Senso in their daily lives (especially in noise)? It is hypothesized that one possibility is that the unique temporal characteristics of the amplifier

of the Senso may not have performed to its optimum capability in the way this investigation was designed. That is, the speech enhancement algorithm within the Senso requires up to 30 seconds for full activation. In this study, the duration of the signal(s) (i.e., speech and noise) was typically between 5 to 10 seconds. It is possible that the relatively short duration of the noise did not activate the speech enhancement algorithm of the Senso to provide the release from masking of the noise that it may be capable of providing.

To test this hypothesis, a follow-up study is being performed to evaluate if the noise condition may have impacted the results of the present study. In the follow-up study, the noise is constantly present in the background. Initial findings show a significant difference in speech recognition performance between the Senso and the subjects' current hearing aids.

Another possible reason for the lack of agreement between the objective and subjective measures is the Hawthorne effect. The Hawthorne effect refers to changes in a subject's behavior simply because the subject knows that he or she is participating in an experiment. This can pose a problem for internal validity because it can serve as an alternative explanation to the treatment effect (Ventry and Schiavetti, 1980). That is, it is possible that the subjects preferred the experimental hearing because they were not "blinded" as to which was the experimental and current hearing aid condition. Clearly, the Hawthorne effect is certainly possible as a means to explain the lack of agreement between the generally positive subjective preference for the Senso in comparison to the generally equivalent performance on objective measures. However, it must be remembered that at Site I, the subjective measures (APHAB and 24-item questionnaire) did not indicate a strong preference for the Senso. None of the four subscales of the APHAB favored the Senso and only three of the 24 items of the questionnaire pointed to a preference for the Senso. Thus, it does not appear as if the Hawthorne effect, if present, had a major impact in the results reported for Site I. At Site II, it was found that the mean benefit score for the Senso was significantly better than the current hearing aid for the EC and RV subscales. In addition, at Site II, 13 of the 24 questions revealed a preference for the Senso, while significant advantages were not present for any of the objective measures (SPIN and HINT) at any of the presentation levels. If the Hawthorne effect was present, it was more likely to have occurred at Site II than Site I. However, it must be emphasized

that the vast majority of subjects used in the present investigation have participated in a number of previous studies at both sites in which they did not report subjective preferences for the experimental hearing aid condition. In order to address this concern, the hearing aid experimental treatments would need to be double-blinded so that neither the subject nor the experimenter was knowledgeable as to which experimental treatment was being evaluated. While this is a relatively easy goal to accomplish—for example, in the efficacy of pharmaceutical treatments (i.e., use of a placebo)—it becomes very difficult to accomplish, for obvious reasons, in hearing aid research.

Lack of a Volume Control

Finally, the subjects were asked if they found the lack of a volume control on the Senso appealing. Table 6 reports that at Site I, eight subjects (32%) found the lack of a volume control to be either "very appealing" (N = 1) or "somewhat appealing" (N = 7). On the other hand, 13 subjects (52%) found the lack of a volume control to be either "somewhat unappealing" (N = 8) or "very unappealing" (N = 5). Four subjects (16%) felt that the lack of a volume control did not make a difference. At Site II, nine subjects (36%) found the lack of a volume control to be either "very appealing" (N = 4) or "somewhat appealing" (N = 5). On the other hand, nine subjects (36%) found the lack of a volume control to be either "somewhat unappealing" (N = 8) or "very unappealing" (N = 1). Seven subjects (28%) felt that the lack of a volume control did not make a difference. Combining the two sites revealed that 17 (34%) subjects reported the lack of a volume control to be "very" or "somewhat" appealing, while 22 (44%) subjects reported that it was "somewhat" or "very" unappealing. This finding

Table 6   Summary of the Responses to the Questionnaire Concerning the Importance of a Lack of a Volume Control on the Experimental Hearing Aids

| Site | | Combined | Response |
I	II		
1	4	5	Very appealing
7	5	12	Somewhat appealing
4	7	11	No difference
8	8	16	Somewhat unappealing
5	1	6	Very unappealing

is in agreement with the results of Knebel and Bentler (1998), who reported that 50 percent of their subjects stated that they would have preferred a volume control on either the Widex Senso or Oticon DigiFocus digital hearing aids.

The findings in Table 6 are consistent with the clinical experiences of the authors. That is, experienced hearing aid users who had a volume control tend to prefer hearing aids incorporating a volume control. This should be a major concern to manufacturers who continue to insist on introducing hearing aids without a volume control to a market that is dominated by previous users.

CONCLUSION

The major findings of this study revealed that:

1. The mean performance of the Senso was found to be significantly better than the mean performance of the subjects' current aids at Site I for the LP-items and the total percent score of the R-SPIN when the input signal was 50 dBA. For the HP-items, the overall mean performance of the Senso was significantly better than the subjects' current hearing aids at an input level of 50 dBA. There were no significant differences in performance between the Senso and the subjects' current hearing aids for the LP-item scores at input levels of 65 and 80 dBA at Site I or at any input level at Site II. For the HP-item scores, significant differences between hearing aids were not present for input levels of 65 and 80 dBA. For the total percent score, there were no significant differences in performance between the Senso and the subjects' current hearing aids at input levels of 65 and 80 dBA at Site I or at any input level at Site II.

2. There were no significant overall differences in performance on the HINT test between the Senso and the subjects' current hearing aids. In addition, the mean HINT threshold was significantly poorer at an input level of 50 dBA than at either of the other two input levels. Significant differences in performance between the Senso and the subject's current hearing aids were not found at input levels of 50, 65, and 80 dBA at Site I or II.

3. The mean benefit score for the Senso was found significantly better than the subjects' current hearing aids for the EC and RV subscales at only Site II. Significant differences between the hearing aid conditions were not found at either site for the BN and AV subscales.

4. The results for one of the questionnaires used in this study reported greater preference for the Senso for 3/24 questions at Site I and 15/24 questions at Site II after wearing the Senso hearing aids for 30 days. Also, 60 percent of the subjects at the two sites reported that the Senso was either "significantly better" or "better" than their current hearing aids, while 16 percent reported that the Senso was "significantly poorer or "poorer" than their current hearing aids.

5. Finally, the data from this study suggest that subjects differed markedly in their opinions regarding the Senso's lack of a volume control. That is, 52 percent of the subjects at Site I and 36 percent of the subjects at Site II reported that the lack of a volume control on the Senso was either "somewhat unappealing" or "very unappealing." On the other hand, 32 percent of the subjects at Site I and 36 percent of the subjects at Site II reported that the lack of a volume control was "very appealing" or "somewhat appealing." Further study on candidacy and counseling issues for "automatic" volume control hearing aids is warranted.

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Appendix A   Individual SPIN Scores (Low Predictability [LP], High Predictability [HP], and Total [T]) for Overall Input Levels of 50, 65, and 80 dBA (+8 S/N) for Sites I and II for Senso and Subjects' Own Aid, Listed by Type of Signal Processing (SP)

| | | Own Aid | | | | | | | | | Senso | | | | | | | | |
| | | 50 | | | 65 | | | 80 | | | 50 | | | 65 | | | 80 | | |
	SP	LP	HP	T	LP	HP	T	LP	HP	T	LP	HP	T	LP	HP	T	LP	HP	T
Site I																			
GC	2B LKP	18	24	42	21	25	46	20	23	43	23	25	48	17	24	41	21	25	46
NL	2B LKP	12	25	37	21	24	45	18	24	42	18	24	42	13	24	37	16	24	40
LL	2B LKP	6	21	27	18	25	43	16	24	40	16	25	41	15	23	38	15	25	40
DR	2B LKP	20	25	45	20	26	46	15	25	40	22	25	47	20	24	44	13	24	37
TC	2B LKP	10	24	34	21	25	46	16	25	41	20	25	45	19	25	44	16	25	41
JH	2B LKP	6	21	27	21	25	46	22	25	47	6	20	26	11	24	35	19	25	44
LA	2B LKP	12	23	35	12	25	37	14	25	39	15	25	40	14	25	39	13	24	37
JM	2B LKP	5	24	29	19	25	44	16	25	41	18	25	43	15	24	39	17	25	42
AH	2B LKP	18	25	43	17	25	42	19	25	44	17	25	42	20	25	45	13	22	35
RE	2B VKP	16	25	41	21	24	45	12	24	36	17	25	42	17	24	41	21	24	45
AK	1B LKP	9	25	34	20	25	45	15	25	40	19	22	41	17	24	41	17	24	41
SS	1B HKP	14	25	39	14	24	38	17	25	42	16	24	40	19	25	44	17	25	42
HF	1B HKP	17	23	40	21	25	46	13	25	38	15	25	40	19	24	43	12	25	37
MU	2B LKP	17	25	42	22	25	47	17	25	42	21	25	46	18	25	43	17	25	42
FB	1B LKP	3	15	18	11	24	35	14	25	39	4	19	23	10	25	35	15	25	40
LO	2B LKP	1	13	14	12	24	36	5	25	30	10	21	31	13	24	37	15	25	40
JG	2B LKP	16	25	41	19	25	44	15	22	37	22	25	47	20	25	45	18	25	43
AP	1B LKP	19	25	44	20	25	45	19	25	44	15	25	40	18	25	43	19	25	44
RR	2B LKP	12	25	37	15	25	40	13	25	38	17	25	42	19	24	43	18	24	42
BA	2B LKP	8	25	33	15	24	39	15	25	40	12	25	37	14	25	39	16	25	41
BL	2B VKP	14	21	35	17	21	38	17	25	42	10	21	31	10	24	34	13	21	34
LD	2B LKP	0	16	16	1	25	26	14	25	39	6	16	22	3	20	23	5	21	26
LR	2B LKP	4	24	28	5	25	30	2	23	25	4	24	28	3	23	26	4	20	24
PV	2B VKP	11	25	36	13	25	38	17	24	41	11	24	35	15	25	40	16	25	41
MS	2B VKP	0	14	14	20	24	44	9	22	31	6	22	28	12	23	35	12	24	36
Site II																			
JB	2B VKP	14	24	38	11	24	35	16	25	31	9	25	34	13	25	38	18	25	43
WM	2B VKP	9	24	33	11	24	35	11	23	34	10	24	34	15	25	40	15	24	39
DG	OL	14	24	38	10	21	31	4	24	28	12	22	34	9	21	30	15	24	39
EH	2B LKP	7	22	29	11	24	35	13	24	37	11	20	31	19	22	41	18	24	42
JT	2B VKP	3	19	22	7	22	29	6	19	25	7	20	27	11	19	30	11	21	32
RS	2B VKP	5	19	24	15	23	38	15	23	38	9	21	30	15	24	39	16	24	40
MH	OL	10	16	26	7	21	28	10	22	32	13	22	35	20	24	44	12	22	34
RR	2B LKP	2	13	15	5	14	19	4	15	19	3	13	16	3	14	19	4	16	20
LW	2B VKP	5	19	24	11	21	32	12	22	34	12	19	31	13	19	32	13	22	35
JH	2B VKP	14	21	35	17	24	41	11	21	32	12	24	36	17	25	42	15	24	39
SJ	2B LKP	3	12	15	9	13	22	5	20	25	4	10	15	5	13	18	11	16	27
LO	2B VKP	8	19	27	15	22	37	14	24	38	10	21	31	14	22	36	14	19	33
WS	2B VKP	9	23	32	13	22	35	21	24	45	11	23	34	14	21	35	17	22	39
RL	2B LKP	8	21	29	13	20	33	18	22	40	11	22	33	14	17	31	15	23	28
JG	2B LKP	5	19	24	9	22	31	14	23	37	5	19	24	11	21	32	16	19	35
RG	2B LKP	5	20	26	13	20	33	11	23	34	8	19	27	12	22	34	9	23	32
OG	OL	4	20	24	11	23	34	17	25	42	6	22	28	12	22	34	15	23	38
JL	2B LKP	4	16	20	12	18	30	11	21	33	10	17	27	13	16	29	7	22	29
MM	2B LKP	10	21	22	16	21	37	17	25	42	11	20	31	12	23	35	16	23	39
LP	OL	7	24	31	15	23	38	15	24	39	9	24	33	19	21	40	14	22	26
BR	2B LKP	14	21	35	17	21	38	17	25	42	15	22	37	15	24	39	14	24	28
WW	2B VKP	10	16	26	12	22	34	15	24	39	9	20	29	10	23	33	12	23	35
SL	2B LKP	9	14	23	14	20	34	21	24	45	11	19	30	13	22	35	14	23	37
BW	OL	6	16	22	13	21	34	12	24	36	9	17	26	13	19	32	8	24	32
LF	OL	15	20	35	19	22	41	12	24	36	14	18	32	15	22	37	15	21	36

1B LKP = single-band, low kneepoint; 1B HKP = single-band, high kneepoint; 2B LKP = two-band, low kneepoint; 2B PKP = two-band, programmable kneepoint; OL = output limiting.

Appendix B   Individual HINT Thresholds for Overall Noise Input Levels of 50, 65, and 80 dBA for Sites I and II for Senso and Subjects' Own Aid, Listed by Type of Signal Processing (SP)

| | SP | Own Aid | | | Senso | | |
		50	65	80	50	65	80
Site I							
GC	2B LKP	−2.0	−0.8	−0.5	−2.5	−5.2	−0.4
NL	2B LKP	0.8	−1.2	2.2	1.5	2.9	5.1
LL	2B LKP	10.7	2.2	7.9	1.8	3.9	3.2
DR	2B LKP	−6.1	−4.2	−4.6	−3.2	−0.7	0.8
TC	2B LKP	0.8	0.8	4.4	0.1	−3.2	−4.4
JH	2B LKP	5.6	−1.1	−1.1	−1.3	0.2	−2.7
LA	2B LKP	4.8	−0.6	2.2	2.0	−3.6	4.8
JM	2B LKP	5.8	2.7	4.8	2.7	4.1	1.3
AH	2B LKP	−1.8	−8.9	−5.2	3.6	2.0	2.2
RE	2B PKP	−3.4	−1.5	−1.1	−1.5	−1.3	−1.3
AK	1B LKP	0.6	3.6	3.3	2.2	−0.1	0.1
SS	1B HKP	−0.8	1.5	2.0	−0.1	−2.5	−2.2
HF	1B HKP	−2.0	2.7	1.0	1.1	0.4	0.4
MU	2B LKP	0.1	−1.5	−1.5	3.4	−0.7	−3.2
FB	1B LKP	12.8	7.9	7.8	6.4	3.2	4.4
LO	2B LKP	6.9	2.2	4.9	4.8	5.1	6.7
JG	2B LKP	−0.8	1.1	5.5	−0.8	0.8	1.8
AP	1B LKP	−3.6	−6.1	−3.7	1.1	−2.5	−0.1
RR	2B LKP	5.3	1.5	6.2	0.9	2.9	3.2
BA	2B LKP	9.3	5.3	5.5	8.4	6.9	7.4
BL	2B PKP	8.6	4.8	−0.8	5.1	1.5	2.8
LD	2B LKP	9.5	3.6	5.1	15.9	13.1	5.7
LR	2B LKP	10.0	3.4	8.4	10.0	8.1	6.1
PV	2B PKP	−0.8	−0.8	0.8	4.4	0.4	−0.1
MS	2B PKP	9.1	6.9	6.9	10.7	5.9	6.0
Site II							
JB	2B PKP	1.9	1.7	1.4	3.1	2.0	−0.4
WM	2B PKP	1.4	0.7	2.7	1.7	−2.3	0.5
DG	OL	2.6	3.0	4.2	3.0	3.3	2.5
EH	2B LKP	1.1	−0.7	1.7	0.7	0.1	1.1
JT	2B PKP	0.7	−1.7	−0.9	−1.1	−2.1	−2.5
RS	2B PKP	1.7	0.9	1.6	1.1	1.3	1.4
MH	OL	2.7	3.7	5.7	1.5	2.6	5.0
RR	2B LKP	7.1	7.3	7.3	4.8	4.1	4.3
LW	2B PKP	2.1	1.1	2.9	2.3	2.7	4.1
JH	2B PKP	2.9	0.7	1.8	2.7	1.1	2.3
SJ	2B LKP	9.5	9.2	9.6	7.0	7.1	7.0
LO	2B PKP	2.3	−2.1	1.8	−0.8	1.4	4.5
WS	2B PKP	4.7	0.3	2.2	5.2	−1.1	1.7
RL	2B LKP	3.4	2.8	1.7	2.8	4.1	−1.1
JG	2B LKP	5.5	1.4	4.5	1.4	−0.8	2.2
RG	2B LKP	3.7	−1.7	−0.7	2.2	2.1	4.1
OG	OL	4.1	1.9	3.2	4.1	2.4	4.1
JL	2B LKP	6.7	1.8	3.4	5.5	−0.6	2.3
MM	2B LKP	1.8	−0.7	1.8	2.3	−1.1	−0.1
LP	OL	3.1	1.7	4.5	2.1	6.5	4.5
BR	2B LKP	−0.7	−0.8	−4.2	2.3	−1.1	−2.1
WW	2B PKP	3.1	2.7	1.5	−0.1	2.5	3.1
SL	2B LKP	2.1	1.1	2.9	2.7	3.1	4.1
BW	OL	4.8	−0.1	−1.7	2.6	4.1	1.1
LF	OL	−1.8	0.7	3.1	2.1	2.8	4.1

1B LKP = single-band, low kneepoint; 1B HKP = single-band, high kneepoint; 2B LKP = two-band, low kneepoint; 2B PKP = two-band, programmable kneepoint; OL = output limiting.

**Appendix C   APHAB Benefit Scores for Ease of Communication (EC),
Background Noise (BN), Reverberant Environments (RV), and Aversiveness to Sounds (AV)
for Sites I and II for Senso and Subjects' Own Aid, Listed by Type of Signal Processing (SP)**

		Own Aid				Senso			
	SP	EC	RV	BN	AV	EC	RV	BN	AV
Site I									
GC	2B LKP	41.8	46.0	35.5	0.2	39.7	35.5	41.8	12.7
NL	2B LKP	29.2	10.2	−43.3	−46.0	42.0	−2.6	−45.3	−50.5
LA	2B LKP	25.2	35.8	47.8	−33.8	33.8	50.2	52.0	−60.7
RE	2B LKP	9.8	21.0	17.0	−0.7	7.7	18.8	14.8	−0.7
AK	2B LKP	12.8	20.7	20.7	4.3	4.5	14.5	22.8	6.5
SS	2B LKP	26.2	50.0	44.2	−12.7	28.0	58.7	43.0	−2.2
HF	2B LKP	50.3	30.2	6.7	−3.0	33.3	17.4	2.2	10.0
MU	2B LKP	26.3	37.3	18.0	−14.5	40.8	37.5	25.2	−54.0
FB	2B LKP	11.7	8.3	16.3	−1.8	12.0	20.8	10.3	0.0
AP	2B VKP	19.2	21.3	26.8	−35.7	21.3	20.4	23.0	−14.8
RR	1B LKP	46.0	68.2	26.8	−2.5	48.2	74.7	39.3	−62.7
BL	1B HKP	26.3	28.5	34.8	−32.0	51.3	59.5	37.0	−21.7
LD	1B HKP	86.7	65.8	59.7	1.8	83.0	42.8	47.2	−53.7
PV	2B LKP	31.5	58.0	33.2	−30.8	35.8	58.0	49.8	−32.8
MS	1B LKP	33.5	37.5	47.7	−8.0	35.7	37.5	35.3	−8.0
LL	2B LKP	40.0	47.7	24.8	6.3	49.5	64.8	58.5	32.8
DR	2B LKP	25.3	35.3	43.8	0.0	10.1	33.0	48.2	−2.2
TC	1B LKP	52.8	53.8	39.7	−5.8	43.7	33.0	12.5	−9.8
JH	2B LKP	18.3	27.0	25.0	−2.2	18.3	42.0	26.8	0.0
JM	2B LKP	40.0	64.3	66.7	−6.5	40.0	60.0	56.0	−2.2
AH	2B VKP	`44.0	49.8	41.5	−4.8	44.0	37.3	39.3	−7.4
BA	2B LKP	79.8	34.8	52.0	−16.2	77.2	29.6	74.4	9.0
LO	2B LKP	74.3	24.3	20.7	−37.8	59.7	26.3	12.3	−37.8
JG	2B VKP	10.5	45.8	27.2	6.2	16.7	41.5	33.5	6.5
LR	2B VKP	25.5	18.5	24.5	−11.0	25.5	18.5	20.3	−78.0
Site II									
JB	2B VKP	37.0	64.3	58.2	16.1	37.4	62.3	57.9	−4.4
WM	2B VKP	17.6	36.8	43.4	4.1	19.4	36.8	41.2	4.1
DG	OL	21.0	22.8	33.2.	−8.2	19.0	37.5	37.5	6.1
EH	2B LKP	14.8	20.5	16.3	−65.0	19.1	43.3	28.8	−56.7
JT	2B VKP	45.2	72.2	44.2	−28.2	43.4	66.2	42.0	−36.9
RS	2B VKP	2.5	2.5	2.1	12.6	27.5	29.4	8.5	−35.2
MH	OL	−16.8	−10.7	0.0	7.6	10.7	16.7	−4.2	−1.9
RR	2B LKP	50.4	49.3	41.3	−41.9	54.7	61.8	58.0	−29.4
LW	2B VKP	33.5	47.8	31.0	−8.5	37.9	52.0	41.5	−23.1
JH	2B VKP	0.0	8.3	8.3	−36.7	18.7	10.8	23.1	−20.0
SJ	2B LKP	74.8	67.8	55.8	−61.8	70.5	77.9	53.8	−45.5
LO	2B VKP	41.6	30.7	41.3	−62.2	33.5	63.0	61.7	−60.2
WS	2B VKP	19.2	43.1	41.6	−26.2	27.5	45.6	50.0	−17.8
RL	2B LKP	38.5	41.2	30.3	−23.3	42.0	48.3	36.3	−14.2
JG	2B LKP	18.8	41.9	38.2	2.6	29.1	56.7	60.9	20.7
RG	2B LKP	30.9	33.9	25.1	−12.1	29.3	37.3	26.0	0.3
OG	OL	19.4	8.9	39.0	−16.8	26.9	3.2	30.4	−37.7
JL	2B LKP	41.5	42.9	41.9	−27.6	47.9	38.9	49.5	−24.6
MM	2B LKP	9.0	23.4	33.2	−45.6	16.9	33.7	29.1	−59.4
LP	OL	8.8	32.5	18.9	−27.7	20.5	37.6	19.3	3.2
BR	2B LKP	20.4	51.0	55.5	−26.0	25.5	61.6	54.1	−22.6
WW	2B VKP	30.3	47.0	25.5	−21.6	35.4	48.6	28.0	−21.7
SL	2B LKP	43.7	40.4	13.6	−2.4	56.9	53.3	15.4	2.9
BW	OL	17.4	18.6	29.0	−43.6	20.2	20.7	31.9	−44.6
LF	OL	36.4	38.1	34.5	−30.5	36.9	31.0	10.8	−60.1

1B LKP = single-band, low kneepoint; 1B HKP = single-band, high kneepoint; 2B LKP = two-band, low kneepoint; 2B PKP = two-band, programmable kneepoint; OL = output limiting.