The Effects of Expansion on the Objective and Subjective Performance of Hearing Instrument Users

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Abstract

The present study investigated the effects of expansion on the objective and subjective performance of 20 hearing instrument users fitted binaurally with digital ITE products. Objective performance was evaluated in quiet using the Connected Speech Test and in noise using the Hearing in Noise Test. Subjective performance was evaluated in two ways: (a) by having each participant rate their satisfaction regarding the amount of noise reduction they perceived in each expansion condition on a daily basis and (b) by having each participant indicate which expansion condition they preferred following the completion of a two-week trial. Results indicated that expansion significantly reduced low-level speech perception performance; however, satisfaction and preference ratings significantly increased when using expansion. The effect of degree of hearing loss, expansion kneepoint, and expansion ratio on the effectiveness of expansion for a given listener was discussed.

Key Words: Compression, expansion, hearing aids

Abbreviations: CST = Connected Speech Test; HINT = Hearing in Noise Test; NAL-R = National Acoustic Laboratory Revised; NAL–NL1 = National Acoustic Laboratory nonlinear; WDRC = wide dynamic range compression

Sumario

El presente estudio investigó los efectos de expansión en el desempeño objetivo y subjetivo de 20 usuarios de instrumentos auditivos adaptados binauralmente con productos digitales de tipo ITE. El desempeño objetivo se evaluó en silencio utilizando la Prueba de Lenguaje Conectado, y en ruido, usando la Prueba de Audición en Ruido. El desempeño subjetivo se evaluó de dos maneras: (a) haciendo que cada participante juzgara su satisfacción en relación a la reducción del ruido que percibieron en cada condición de expansión en forma diaria, y (b) haciendo que cada participante indicara cuál condición de expansión preferían, luego de completar un período de prueba de dos semanas. Los resultados indicaron que la expansión reducía satisfactoriamente el desempeño en la percepción del lenguaje a bajo volumen; sin embargo, los juicios de satisfacción y preferencia aumentaron significativamente cuando se utilizaba la expansión. Se discutió el efecto del...
Wide dynamic range compression (WDRC) hearing instruments provide reduced gain for high-level input signals and increased gain for low-level input signals (Johnson, 1993; Killion, 1996). Input signal levels below the kneepoint of compression receive the maximum amplification allowable by the hearing instrument. Providing maximum amplification for low-level signals may improve speech intelligibility by increasing the audibility of speech cues necessary for feature identification. However, providing maximum amplification for low-level signals may also increase the audibility of low-level environmental noises as well as noises generated by the hearing instrument (Ricketts and Henry, 2002).

Noise generated from within the hearing instrument typically originates from the microphone (Kuk, 2002) and is approximately 20 dB SPL in most modern devices (Holube and Velde, 2000). Internal noise may be amplified by the hearing instrument and become audible to the listener (Kuk, 2002), thereby creating the complaint that WDRC hearing instruments are abnormally noisy when used in low-level environments (Venema, 1998; Ghent et al, 2000). The amplification of microphone noise may be particularly bothersome for listeners with hearing thresholds at or near normal for some frequency regions (Holube and Velde, 2000).

Villchur (1973) observed that excessive amplification of low-level inputs was an undesirable by-product of compression and suggested that a decrease in amplification for low-level inputs may alleviate this problem in hearing instruments. Technology designed to reduce the amount of amplification of low-level inputs is known as expansion (Kuk, 2002). Expansion is opposite to wide dynamic range compression in that signals below the compression kneepoint receive reduced gain rather than maximum gain (Venema, 2000); therefore, the audibility of low-level environmental noises as well as noises generated by the hearing instrument should be reduced when using expansion (Venema, 1998; Ghent et al, 2000; Kuk, 2002).

Expansion is currently recommended for WDRC hearing instrument users with near normal thresholds to alleviate complaints of noise when in low-level environments (Venema, 2000). However, research regarding the effects of expansion has been limited. Ghent, Nilsson, and Bray (2000) investigated the effectiveness of expansion with digital hearing instruments. Results demonstrated that expansion did reduce the amplification of low-level input signals, thereby potentially reducing audibility of low-level environmental noises as well as noises generated by the hearing instrument. However, decreasing the amplification of low-level signals may also reduce the audibility of low-level, high-frequency speech cues necessary for accurate speech recognition. Consequently, expansion may provide improved sound quality at the cost of reduced recognition of low-level speech. In a preliminary investigation, Plyler (2002) found that expansion degraded the recognition of low-level speech while improving hearing instrument sound quality in some listeners with hearing impairment. The results also suggested that listeners with poorer hearing sensitivity may receive greater objective and subjective benefit from expansion than listeners with milder degrees of hearing loss.
The present study was undertaken to investigate the effects of expansion on the objective and subjective performance of hearing instrument users with varying degrees of hearing loss. The following research questions were addressed: (1) Does expansion affect the recognition of low-level speech in quiet and in noise? (2) Are listeners more satisfied with the amount of low-level noise reduction provided by the hearing instrument when using expansion? (3) Does expansion affect overall listener preference? and (4) Are the effects of expansion related to the degree of hearing loss of the listener?

METHODS

Participants

Twenty adults participated in this experiment. The participants were equally divided into two groups [Group A (52–81 years of age) and Group B (32–85 years of age)]. The criteria for inclusion in Group A included: (1) sensorineural hearing impairment with no more than a 15 dB HL difference in pure-tone thresholds at any octave frequency from 250 through 8000 Hz between ears (ANSI S3.6-1996); (2) normal appearance of ear canal and pinna; (3) normal tympanograms bilaterally; (4) no air-bone gaps greater than 10 dB; (5) current binaural hearing instrument user; and (6) two adjacent hearing thresholds better than 40 dB HL from 250 through 1000 Hz. The inclusion criteria for Group B differed from that of Group A in one aspect: two adjacent hearing thresholds were poorer than 40 dB HL from 250 through 1000 Hz (Figure 1). All qualification and experimental testing was conducted in a sound-treated examination room (Industrial Acoustic) with ambient noise levels suitable for testing with ears uncovered (ANSI S3.1-1991).

Stimuli

The Connected Speech Test (CST) (Cox et al, 1987; Cox et al, 1988) and the Hearing in Noise Test (HINT) (Nilsson et al, 1994) served as the stimuli. The CST is a sentence recognition test using everyday connected speech. The CST consisted of 28 pairs of passages (24 test and 4 practice pairs), and each passage pair contained 50 key words.

Figure 1. Mean binaural air-conduction thresholds and standard deviations of the participants in each group.

The recommended key word method of scoring was utilized to determine the percentage of key words correctly identified for each participant. The HINT consisted of 25 lists of 10 English sentences. An adaptive presentation was utilized to determine the sentence reception threshold in terms of signal-to-noise ratio for each participant using sentence blocks. All speech stimuli and background noise were produced by a compact disc player and routed through a two-channel diagnostic audiometer (GSI-61) to a loudspeaker located in the sound-treated examination room. The output levels of the speech stimuli and background noise were calibrated at the vertex of the listener and were checked periodically throughout the experiment.

Hearing Instruments

Each hearing instrument utilized in the present study was a digital in-the-ear hearing instrument with single-channel WDRC processing and multiple memory capability (Starkey Endeavour). Audiometric data and uncomfortable loudness level data were used to program each hearing instrument using the NAL-NL1 fitting strategy (Byrne et al, 2001). Two memories of the digital hearing instruments were programmed for each participant. All fitting parameters of Memory
1 were identical to all fitting parameters of Memory 2; however, expansion was activated in only one of the two memories in a random order. Therefore, each hearing instrument had one memory in which expansion was activated and one memory in which expansion was deactivated. All other fittings parameters were held constant across the two memories. The expansion kneepoint was 50 dB SPL, and the expansion attack and release times were 512 msec. The expansion ratio was 0.5:1. The noise suppression feature and the volume control were deactivated for the entire experiment; therefore, the volume control setting was unchanged during all evaluations of the expansion feature.

**Hearing Instrument Fitting**

Binaural probe microphone measures were conducted on each subject to verify match to the NAL-R target (Byrne and Dillon, 1986) (±6 dB from 500–4000 Hz) using a swept pure tone at 65 dB SPL (note: NAL-NL1 was used to derive and set the fitting parameters; however, NAL-R was used to verify the target match for a midlevel input due to equipment limitations. NAL-NL1 and NAL-R should be comparable for a midlevel input). Probe microphone measures were also obtained with the loudspeaker deactivated for each expansion condition and in the unaided condition to verify appropriate functioning of the expansion feature (Mueller, 2001). Binaural probe microphone measurements were obtained at the input signal levels used in the present study (40, 50, and 60 dB SPL) with the expansion feature activated and with the expansion feature deactivated. All probe microphone measurements consisted of 65 data points measured in 1/12th octave steps over a frequency range of 200 Hz to 8000 Hz. Data for output levels at the tympanic membrane stored in the Audioscan RM500 were downloaded to a personal computer for subsequent data analysis. Following the fitting, each participant was given a schedule detailing his or her use pattern for each memory to ensure each expansion condition was utilized equally during the trial period. Each participant then utilized the hearing instruments for a two-week period before returning to the laboratory for the objective and subjective evaluations.

**Objective Evaluation**

One purpose of the present study was to determine if expansion technology affected the recognition of low-level speech in quiet and in noise. Participants were seated one meter from a loudspeaker located at 0º azimuth in the sound-treated room. The CST and the HINT were administered at 40, 50, and 60 dB SPL for the two expansion conditions. Although the CST is typically conducted using a fixed signal-to-noise ratio, no background noise was utilized in the present study in order to evaluate the effects of expansion in a quiet setting. In addition, the HINT protocol utilized in the present study reflected a slight modification of the original HINT protocol in that noise levels were varied and speech levels were fixed. This protocol variation ensured that noise levels were maintained below the kneepoint of expansion when using the 40 dB SPL signal and allowed for the evaluation of expansion in a low-level environment.

Two CST and two HINT trials were conducted for each expansion condition at each presentation level. An average of the two trials served as the mean CST or mean HINT score for that participant in the given condition. Prior to data collection, an experimental schedule was generated for each participant listing a completely randomized assignment for expansion condition, CST passage, and HINT sentence list.

**Subjective Evaluation**

A second purpose of the present study was to determine if listeners were more satisfied with the amount of low-level noise reduction provided by the hearing instrument when using expansion and to determine if expansion affected overall listener preference. Each participant utilized the hearing instruments for a two-week period and was asked to complete a daily subjective evaluation of each expansion condition (Appendix). For each memory, participants were asked to rate their satisfaction regarding the amount of background noise reduction they perceived in two environments: in quiet and in everyday low-level listening environments.

Participants were instructed to conduct their quiet environment evaluations while
sitting quietly, reading a book or magazine, or just relaxing. Participants were instructed to conduct their everyday low-level listening environment evaluations while paying close attention to soft sounds such as having a quiet conversation with one other person, listening to leaves rustling, watching television at a low volume, et cetera. All volume controls were deactivated; therefore, participants conducted each subjective rating with the volume control at the same setting for each memory. Each expansion condition was rated twice a day for ten of the fourteen days, therefore, each participant rated each expansion condition a total of 20 times for each listening environment. Following the completion of the two-week period, each participant was asked to indicate which expansion condition they preferred overall when listening in quiet and when listening in everyday low-level environments to determine if the expansion feature affected overall listener preference.

RESULTS

Probe Microphone Measures

Binaural probe microphone measures obtained with the loudspeaker deactivated were averaged across ears for the 20 participants for the unaided condition and for the two expansion conditions to verify appropriate functioning of the expansion feature (Figure 2). Mean in situ levels were calculated for the unaided condition and for each expansion condition by averaging the in situ levels at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The mean in situ level was 19.6 dB SPL for the unaided condition, 25.7 dB SPL for the expansion on condition, and 32.4 dB SPL for the expansion off condition. Results of a paired samples t-test demonstrated that the mean in situ levels were significantly greater for the expansion off condition than the expansion on condition when the loudspeaker was deactivated (t[19] = 8.158; p < 0.05).

Binaural probe microphone measures obtained at 40, 50, and 60 dB SPL were also averaged across ears for the 20 participants for each expansion condition (Figures 3–5). A mean in situ level was then calculated for each expansion condition at each intensity level by averaging the in situ levels at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Results of a paired samples t-test demonstrated that the mean in situ levels were significantly greater for the expansion off condition than the expansion on condition when using a 40 dB SPL input signal (t[19] = 6.513; p < 0.05). Results further demonstrated that the mean in situ levels were similar for each expansion condition when using the 50 dB SPL input signal (t[19]}
Results of the probe microphone testing indicated that the expansion feature was functioning appropriately for each hearing instrument utilized in the present study.

Objective Evaluation

Performance in Quiet

One purpose of the present study was to determine if expansion affected the recognition of low-level speech in quiet and in noise. The Connected Speech Test (CST) was conducted at three levels (40, 50, and 60 dB SPL) for the two experimental conditions (expansion off and expansion on) to assess listener performance in quiet. CST scores were then averaged across both groups for each expansion condition and each intensity level (Figures 6 and 7). Prior to statistical analysis, individual percent correct scores were converted to rationalized arcsine transform units (RAUs) to stabilize error variance (Studebaker, 1985). A three-way analysis of variance was performed to
evaluate the effects of expansion, intensity level, and hearing sensitivity on performance in quiet. The dependent variable was CST score. The within-subject factors were expansion with two levels (off and on) and intensity level with three levels (40, 50, and 60 dB SPL). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for expansion ($F[1,18] = 16.169, p < 0.05$), intensity level ($F[1,18] = 90.841, p < 0.05$), and for group ($F[1,18] = 76.389, p < 0.05$).

The three-way analysis of variance also revealed significant interactions for intensity level by group ($F[1,18] = 3.577, p < 0.05$) and intensity level by expansion ($F[1,18] = 3.564, p < 0.05$). A paired samples t-test was conducted to further investigate the intensity level by expansion interaction. Results indicated that performance in quiet was significantly poorer for the expansion on condition than the expansion off condition when using the 40 dB SPL input signal ($t[19] = -4.003; p < 0.05$) and the 50 dB SPL input signal ($t[19] = -2.019; p < 0.05$). Performance in quiet was similar for each expansion condition when using the 60 dB SPL input signal ($t[19] = -1.635; p > 0.05$).

Results of testing in quiet indicated that performance improved as intensity level increased for both groups; however, listeners with less hearing impairment performed significantly better than listeners with more severe hearing impairment. Results further indicated that activation of the expansion feature significantly reduced listeners’ performance in quiet when the input signal level was at or below the kneepoint of expansion.

**Performance in Noise**

The Hearing in Noise Test (HINT) was conducted at three speech levels (40, 50, and 60 dB SPL) for each participant to assess listener performance in noise. HINT scores were then averaged across both groups for each expansion condition and each intensity level (Figures 8 and 9). A three-way analysis of variance was performed to evaluate the effects of expansion, intensity level, and hearing sensitivity on performance in noise. The dependent variable was HINT signal-to-noise ratio. The within-subject factors were expansion with two levels (off and on), and intensity level with three levels (40, 50, and 60 dB SPL). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for expansion ($F[1,18] = 35.882, p < 0.05$), intensity level ($F[1,18] = 65.015, p < 0.05$), and for group ($F[1,18] = 17.314, p < 0.05$).

The three-way analysis of variance also revealed a significant intensity level by expansion ($F[1,18] = 11.781, p < 0.05$) interaction. A paired samples t-test was conducted to further investigate the intensity level by expansion interaction. Results indicated that performance in noise was significantly poorer for the expansion on condition than the expansion off condition at the 40 and 50 dB SPL input signals ($t[19] = -4.003; p < 0.05$ and $t[19] = -2.019; p < 0.05$, respectively) but not at the 60 dB SPL input signal ($t[19] = -1.635; p > 0.05$).

Results of testing in quiet indicated that performance improved as intensity level increased for both groups; however, listeners with less hearing impairment performed significantly better than listeners with more severe hearing impairment. Results further indicated that activation of the expansion feature significantly reduced listeners’ performance in quiet when the input signal level was at or below the kneepoint of expansion.

**Figure 8.** Mean HINT scores and standard deviations for Group A for the two expansion conditions.

**Figure 9.** Mean HINT scores and standard deviations for Group B for the two expansion conditions.
condition than the expansion off condition when using the 40 dB SPL input signal (t [19] = 5.091; p < 0.05) and the 50 dB SPL input signal (t [19] = 3.955; p < 0.05). Results further demonstrated that performance in noise was similar for each expansion condition when using the 60 dB SPL input signal (t [19] = 0.309; p > 0.05).

Results of testing in noise indicated that performance improved as intensity level increased for both groups; however, listeners with less hearing impairment performed significantly better than listeners with more severe hearing impairment. Results further indicated that activation of the expansion feature significantly reduced listener performance in noise when the input signal level was at or below the kneepoint of expansion.

Subjective Evaluation

Satisfaction Ratings

A second purpose of the present study was to determine if listeners were more satisfied with the amount of low-level noise reduction provided by the hearing instrument when using expansion. Each participant utilized the hearing instruments for a two-week period and completed a daily subjective evaluation of each expansion condition (Appendix). For each expansion condition, participants were asked to rate their satisfaction regarding the amount of background noise reduction they perceived in two environments, in quiet and in everyday low-level environments, using a five-point scale (1 = much too little, 2 = too little, 3 = okay, 4 = too much, 5 = much too much).

From the data collection phase, it was obvious that some individuals felt the expansion feature provided an insufficient amount of noise reduction (rating = 1 or 2) whereas other listeners felt the expansion feature provided an excessive amount of noise reduction (rating = 5 or 4). Both of these instances were viewed as ratings of dissatisfaction with the amount of noise reduction provided by the expansion feature. In order to evaluate the expansion feature in terms of satisfaction versus dissatisfaction, individual satisfaction ratings of 4 or 5 were recoded to ratings of 2 or 1, respectively, to simply reflect dissatisfaction with the expansion feature. Individual satisfaction ratings were then averaged across the ten days and across the two groups for each expansion condition and each listening environment (Figures 10 and 11).

A two-way analysis of variance was performed to evaluate the effects of expansion and hearing sensitivity on satisfaction ratings in quiet. The dependent variable was mean satisfaction rating. The within-subject factor was expansion with two levels (off and on). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effect for

![Figure 10](https://example.com/figure10.png)  
*Figure 10.* Mean satisfaction ratings and standard deviations in quiet for the two expansion conditions.

![Figure 11](https://example.com/figure11.png)  
*Figure 11.* Mean satisfaction ratings and standard deviations in everyday low-level environments for the two expansion conditions.
expansion ($F[1,18] = 8.069, p < 0.05$). However, main effects for group ($F[1,18] = 0.246, p > 0.05$) and for the expansion by group interaction ($F[1,18] = 0.628, p > 0.05$) were not significant. These results indicated that listeners in each group were more satisfied with the amount of noise reduction in quiet when expansion was activated.

A two-way analysis of variance was also performed to evaluate the effects of expansion and hearing sensitivity on satisfaction ratings in everyday low-level environments. The dependent variable was mean satisfaction rating. The within-subject factor was expansion with two levels (off and on). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effect for expansion ($F[1,18] = 38.736, p < 0.05$) and for the expansion by group interaction ($F[1,18] = 11.231, p < 0.05$). However, main effects for group ($F[1,18] = 0.047, p > 0.05$) were not significant. These results indicated that listeners in each group were more satisfied with the amount of noise reduction in low-level environments when expansion was activated. Results further suggested that listeners with less hearing impairment reported a larger satisfaction increase when using expansion in low-level environments than listeners with more severe hearing impairment.

Overall Preference

Another purpose of the present study was to determine if expansion affected overall listener preference. Following the completion of the two-week trial period, each participant was asked to indicate which expansion condition they preferred when listening in quiet and when listening in everyday low-level environments to determine if the expansion feature affected overall listener preference. Preference results are displayed in Figures 12 and 13.

A one-sample chi-square test was conducted to assess whether listeners preferred the expansion on condition, the expansion off condition, or did not have a preference when listening in a quiet environment. The results of the test were significant, $\chi^2(2, N = 20) = 19.9, p < 0.05$. The proportion of listeners that preferred the expansion on condition ($P = .8$) was greater than the hypothesized proportion of .33, while the proportion of listeners that preferred the expansion off condition ($P = .05$) and the proportion that did not have a preference ($P = .15$) were less than the hypothesized proportion of .33. Follow-up testing indicated that the proportion of listeners preferring the expansion on condition differed significantly from the proportion of listeners preferring the expansion off condition, $\chi^2$.
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Follow-up testing further indicated, however, that the proportion of listeners preferring the expansion off condition did not differ significantly from the proportion of listeners that did not have a preference, $\chi^2(1, N = 19) = 8.89, p < 0.05$. These results suggested that listeners preferred the expansion on condition when listening in a quiet environment.

A one-sample chi-square test was also conducted to assess expansion preference when listening in an everyday low-level environment. The results of the test were not significant, $\chi^2(1, N = 20) = 0.2, p > 0.05$. However, examination of the data suggested that expansion preference in a low-level environment may be related to hearing sensitivity of the listener. For example, eight out of ten participants with better hearing sensitivity (Group A) preferred the expansion on condition while two participants had no preference. Conversely, one out of ten participants with poorer hearing sensitivity (Group B) preferred the expansion on condition while nine participants had no preference. Therefore, a two-way contingency table analysis was conducted to determine if expansion preference in a low-level environment was related to hearing sensitivity. The two variables were hearing sensitivity with two levels (Group A and Group B) and expansion preference with two levels (on or no preference). Results indicated that hearing sensitivity and expansion preference were significantly related, Pearson $\chi^2(1, N = 20) = 9.89, p < 0.05$. These results suggested that listeners with better hearing sensitivity were more likely to prefer the expansion on condition than listeners with poorer hearing sensitivity when listening in an everyday low-level environment.

DISCUSSION

Objective Evaluation

One purpose of the present study was to determine if expansion affected the recognition of low-level speech in quiet and in noise. Listeners in both groups performed significantly better in quiet and in noise when the expansion feature was deactivated. Furthermore, activation of the expansion feature significantly degraded speech recognition ability of both groups in quiet and in noise when input levels were at or below the kneepoint of expansion. These results suggest that expansion negatively affects the recognition of low-level speech in quiet and in noise.

Speech recognition deficits observed for stimuli presented below the expansion kneepoint are attributed to reduced audibility of the speech signal during the expansion on condition. As expected, expansion significantly reduced in situ output levels when the input level of the stimulus was below the kneepoint of expansion (Figure 3). As a result, the audibility of speech cues necessary for accurate feature identification were significantly reduced during the expansion on condition, thereby resulting in degraded recognition of low-level speech in quiet and in noise for listeners in each group.

Reduced audibility also explains the speech recognition deficits observed in the expansion on condition for stimuli presented at the kneepoint of expansion. Probe microphone results revealed similar output spectra for each expansion condition when using a calibrated swept tone as the stimulus (Figure 4). The amplitude of the swept tone was constant across frequency (50 dB SPL) and equaled the kneepoint of expansion (50 dB SPL) during each probe microphone measurement. Therefore, similar output spectra should have been obtained for each expansion condition when using the swept tone since the input level prohibited activation of the expansion feature during each measurement.

Output spectra should have differed for each expansion condition when the input stimulus was speech instead of the calibrated swept tone. The amplitude of speech fluctuates over time by approximately 30 dB. Consequently, amplitude variations in the speech waveform resulted in speech levels that were, at times, below the kneepoint of expansion during the presentation of the sentence stimuli, thereby activating the expansion feature. Because of the relatively fast time constant for the expansion system (512 msec), the gain of the hearing aid likely fluctuated based on the short-term amplitude fluctuations of the speech at the nominal level of 50 dB SPL. As a result, the audibility of speech cues necessary for accurate feature identification may have been significantly
reduced during the expansion on condition when speech stimuli were presented at the kneepoint of expansion.

**Subjective Evaluation**

A second purpose of the present study was to determine if listeners were more satisfied with the amount of low-level noise reduction provided by the hearing instrument when using expansion and to determine if expansion affected overall listener preference. Listener satisfaction and listener preference were evaluated in quiet and in everyday low-level listening environments. Participants in both groups reported greater noise reduction satisfaction in each listening environment when using the expansion feature. However, listeners with better hearing sensitivity reported larger satisfaction improvements than listeners with poorer hearing sensitivity when listening in everyday low-level environments. Furthermore, participants in both groups reported an overwhelming preference for the expansion feature when listening in a quiet environment (85%). However, listeners with better hearing sensitivity preferred expansion while listeners with poorer hearing sensitivity reported no preference when listening in an everyday low-level environment. These findings suggest that expansion improves subjective performance for listeners with varying degrees of hearing loss when used in a quiet environment. However, expansion may be more effective for listeners with better hearing sensitivity than listeners with poorer hearing sensitivity when used in everyday low-level environments.

Subjective preference for the expansion condition occurred despite the fact that expansion may significantly reduce the ability to recognize low-level speech in quiet and in noise. Subjective results obtained in quiet may have been affected by instructions given to the listeners. Participants were instructed to note how “loud” the background noise was when sitting quietly, reading a book or magazine, or just relaxing in a very quiet environment. Consequently, it is possible some participants did not listen to speech when evaluating expansion in a quiet setting while others rarely listened to speech at such low levels. In either case, speech recognition deficits would have gone unnoticed and would not be expected to impact subjective results.

However, it is also possible that the noise reduction benefits produced by expansion outweighed the speech recognition deficits produced when listening in a quiet environment given the fact that most listeners preferred the use of expansion.

Speech levels encountered by the listeners may have also affected subjective results obtained in everyday low-level environments. Listeners were instructed to conduct their everyday low-level listening environment evaluations while paying close attention to “soft sounds” when having a quiet conversation with one other person, listening to leaves rustling, watching television at a low volume, etcetera. However, speech levels judged as “soft” by listeners with poorer hearing sensitivity may have been greater than speech levels judged as “soft” by listeners with better hearing sensitivity. As a result, listeners with poorer hearing sensitivity may have rarely encountered everyday listening situations where the input signals were below the kneepoint of expansion whereas listeners with better hearing sensitivity may have frequently encountered everyday listening situations where input signals were below the kneepoint of expansion. Consequently, the expansion feature may become engaged more frequently for some listeners than for other listeners, thereby resulting in variable subjective performance from the end users when listening in low-level environments. Nonetheless, the possible relationship between hearing sensitivity and subjective performance in everyday low-level environments warrants further investigation.

**Degree of Hearing Loss**

Another purpose of the present study was to determine if the effects of expansion were related to the listener’s degree of hearing loss. Expansion is currently recommended for WDRC hearing instrument users with near normal thresholds to alleviate complaints of noise when in low-level environments (Venema, 2000). Results of the present study, however, suggest that the effects of expansion are not related to the degree of hearing loss of the listener. Objective testing demonstrated that expansion degraded speech recognition ability in quiet and in noise for listeners in both groups; however, the speech recognition deficits
produced by the expansion feature were comparable for all listeners. Similarly, subjective testing revealed that listeners in each group reported greater satisfaction ratings and an overall preference for the expansion condition when listening in a quiet setting. Although subjective testing did reveal a possible relationship between hearing sensitivity and subjective performance when listening in low-level environments, the cause of this relationship is unclear and warrants further investigation. These findings suggest that expansion affects the objective and subjective performance of listeners with varying degrees of hearing loss in a similar manner.

**CLINICAL IMPLICATIONS**

Results of the present study indicate that hearing instrument users prefer the use of expansion despite the fact that expansion may significantly reduce the ability to recognize low-level speech in quiet and in noise. These findings are in agreement with previous results reported by Plyler (2002) that suggested that expansion provides improved sound quality at the cost of reduced recognition of low-level speech.

Dispensers should be aware that selection of the expansion parameters may play an important role in determining the effectiveness of the feature for a given listener. For example, expansion may negatively affect the ability to recognize speech over a wider range of input levels if the expansion kneepoint is increased; however, speech recognition degradation may occur over a more limited range of input levels if the expansion kneepoint is reduced. Conversely, subjective performance may be improved by increasing the kneepoint of expansion; however, decreasing the expansion kneepoint may reduce subjective benefit associated with the feature.

Selection of the expansion ratio may also affect performance with the feature. For example, expansion may more negatively affect the ability to recognize low-level speech if the expansion ratio is increased; however, speech recognition degradation may be minimized if the expansion ratio is reduced. Conversely, subjective performance may be improved by increasing the expansion ratio; however, decreasing the expansion ratio may reduce subjective benefit associated with the feature. Future research should investigate the effects of varying the expansion kneepoint and the expansion ratio in order to determine the expansion characteristics that produce the proper balance between speech recognition preservation and subjective benefit.

Lastly, the results of the present study do not agree with conventional thinking regarding the use of expansion. Expansion is currently recommended for listeners with near normal thresholds in order to alleviate complaints of noise when in quiet settings (Venema, 2000). Results of the present study suggest, however, that expansion affects performance and preference similarly, regardless of the degree of hearing loss of the listener. Dispensers should be aware that expansion may be recommended for listeners with varying degrees of hearing loss in order to alleviate the complaints of noise associated with WDRC hearing instruments. Dispensers should be aware that the positive and negative effects of expansion apply not only to listeners with near normal thresholds but to listeners with varying degrees of hearing loss as well.

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**REFERENCES**


APPENDIX

Daily Log

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<th>General Listening Environment</th>
<th>Rate your satisfaction with the amount of background noise reduction (1 = much too little, 2 = too little, 3 = ok, 4 = too much, 5 = much too much) Circle your favorite setting</th>
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<td>Memory 2:_____ COMMENTS:</td>
<td>Memory 1:_____</td>
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