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The Objective and Subjective Evaluation of Low-Frequency Expansion in Wide Dynamic Range Compression Hearing Instruments

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Abstract

The effects of low-frequency expansion on the objective and subjective evaluation of four channel in-the-ear hearing instruments was investigated. Three expansion settings were programmed in each device: expansion off, expansion restricted to channel one, and expansion restricted to channels one and two. Objective evaluations were conducted in quiet (Connected Speech Test) and in noise (Hearing in Noise Test) with speech levels fixed at 40 dB SPL. Subjectively, each participant rated expansion satisfaction in quiet and listening to low-level speech in a sound-treated room then indicated the expansion condition preferred overall. Listeners performed significantly better in quiet and in noise for the Off and Channel 1 conditions than the Channels 1 and 2 condition; however, performance was similar between the Off and Channel 1 conditions. Expansion effects on listener satisfaction ratings depended on the listening environment. Overall, listeners preferred expansion in Channel 1 to expansion in Channels 1 and 2; however, preference was not significantly different between the Channel 1 and Off conditions. Results indicate restricting expansion to 1000 Hz overcomes speech-recognition deficits observed with expansion active across a broader spectrum without significantly reducing subjective benefit or preference.

Key Words: WDRC, wide dynamic range compression, connected speech test, HINT test, expansion, compression, noise reduction

Abbreviations: WDRC = wide dynamic range compression, CST = Connected Speech Test, HINT = Hearing in Noise Test, NAL-NL1 = National Acoustic Laboratories Non-Linear, SNR = signal-to-noise ratio, ANSI = American National Standards Institute

Sumario

Se investigaron los efectos de la expansión en las frecuencias graves sobre la evaluación objetiva y subjetiva de instrumentos auditivos intra-auriculares de cuatro canales. Se programaron cuatro ajustes de expansión en cada dispositivo: expansión apagada, expansión restringida al canal uno, y expansión restringida a los canales uno y dos. Se condujeron evaluaciones objetivas en silencio (Prueba de Lenguaje Conectado) y en ruido (Prueba de Audición en Ruido) con los niveles de lenguaje fijos a 40 dB SPL. Subjetivamente, cada participante calificó la satisfacción en cuanto a la expansión en silencio y escuchando lenguaje a bajo volumen en una cabina sono-amortiguada, y luego expresó la condición de expansión preferida sobre las demás. Los sujetos funcionaron significativamente mejor en silencio y en ruido para las condiciones de apagado y canal 1 que para la condición de canales 1 y 2; sin embargo, el desempeño fue similar entre las condiciones de apagado y canal 1. Los efectos de la expansión sobre la calificación de la satisfacción de los sujetos

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dependieron del ambiente de escucha. Globalmente, los sujetos prefirieron la expansión en el canal 1 y en los canales 1 y 2; sin embargo, la preferencia no fue significativamente diferente entre la condición de canal 1 y apagado. Los resultados indican que la restricción en la expansión a 1000 Hz compensa las deficiencias en el reconocimiento del lenguaje observada con una expansión activa a lo largo de un espectro más amplio, sin reducir significativamente el beneficio subjetivo o la preferencia.

Palabras Clave: WDRC, compresión de rango dinámico amplio, prueba de lenguaje conectado, prueba de HINT, expansión, compresión, reducción del ruido

Abreviaturas: WDRC = compresión de rango dinámico amplio, CST = Prueba de Lenguaje Conectado; HINT = Prueba de Audición en Ruido; NAL-NL1 = Laboratorios Nacionales de Acústica – No Lineal; SNR = tasa señal-ruido; ANSI = Instituto Americano Nacional de Estándares

Wide dynamic range compression (WDRC) hearing instruments provide level-dependent gain in order to increase the audibility of low-level, high frequency speech cues necessary for accurate speech recognition (Johnson, 1993; Killion, 1996). However, signal levels at or below the compression kneepoint receive the maximum amplification available in WDRC instruments, thereby improving the audibility of low-level environmental noises and/or noises generated by the hearing instrument as well. As a result, WDRC hearing instrument users may report an audible "hissing" sound when in low-level environments (Venema, 2000). Expansion was designed to provide reduced gain for signals below the compression kneepoint rather than maximum gain in order to reduce the audibility of these unwanted, low-level signals (Venema, 1998; Ghent et al, 2000; Kuk, 2002). Recent research has demonstrated that single-channel expansion improves subjective performance for WDRC hearing instrument users (Plyler et al, 2005a; Plyler et al, 2006) despite degrading the recognition of low-level speech (Plyler et al, 2005a, Plyler et al, 2005b).

Expansion effects differ if multi-channel expansion is used instead of single-channel expansion. Plyler et al (2007) examined the effects of multi-channel expansion on the objective and subjective performance of twenty current WDRC hearing instrument users fitted binaurally with four-channel digital in-the-ear products (Starkey Axent II). Three memories of each instrument were programmed such that expansion was activated in all four channels, in channels one and two only (<2000 Hz), and deactivated in all four channels across memories. All other fitting parameters were held constant across the three memories. Objective performance was evaluated in quiet using Connected Speech Test (CST) (Cox et al, 1987; Cox et al, 1988) and in noise using the Hearing in Noise Test (HINT) (Nilsson et al, 1994) for speech levels of 40 dB, 50 dB, and 60 dB SPL. Subjective performance was evaluated by having each subject rate their satisfaction regarding the amount of noise reduction they perceived in each expansion condition on a daily basis over a two-week period in real-world listening environments. In addition, each subject was asked to indicate which expansion condition they preferred following the completion of the two-week trial. Objective results in quiet and in noise indicated that restricting expansion to channels one and two significantly improved objective performance relative to the four-channel expansion condition; however, objective results for the restricted condition were significantly poorer than those for the no-expansion condition. Furthermore, subjective results indicated that restricting expansion to channels one and two preserved the subjective performance observed with four-channel expansion without significantly affecting listen-

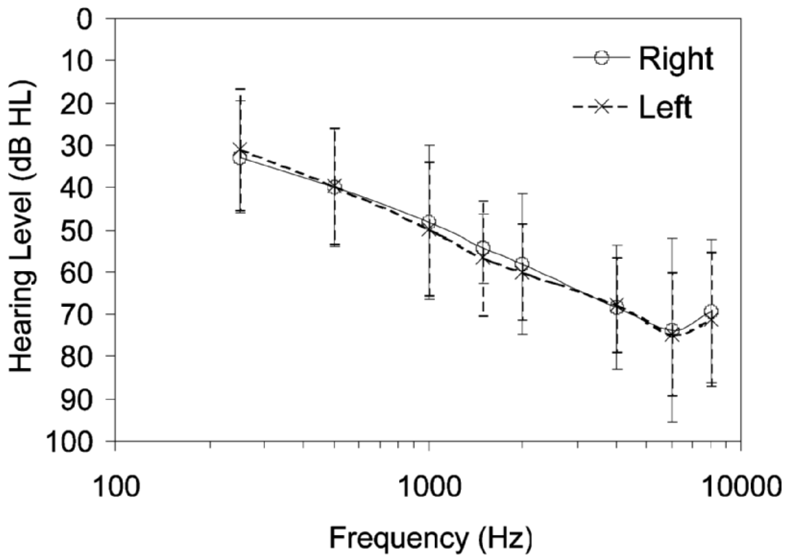

Figure 1. Mean right and left air conduction thresholds and standard deviations of the participants.

er preference. These findings suggested restricting expansion to below 2000 Hz preserves subjective benefit observed when expansion is active across the entire spectrum but does not restore low-level speech recognition observed when expansion is deactivated.

The purpose of the present study was to extend the work of Plyler et al (2007) to determine the effects of low-frequency (<1000 Hz) expansion on the objective and subjective performance of hearing-instrument users. Improving access to speech cues below 2000 Hz may improve audibility of speech cues necessary for accurate feature identification, thereby improving the recognition of low-level speech. Furthermore, in-situ measures suggested that subjective benefit with expansion is attributed to expansion activation below 1235 Hz (Plyler et al, 2007). Given this, it is reasonable to postulate that restricting expansion to lower frequency regions than those examined by Plyler et al (2007) would improve the recognition of low-level speech without significantly reducing subjective benefit for WDRC hearing-instrument users. The following research questions were addressed:

(1) Does low-frequency expansion affect the recognition of low-level speech in quiet and in noise?
(2) Does low-frequency expansion affect satisfaction?
(3) Does low-frequency expansion affect overall listener preference?

METHODS

Participants

Fifteen of the 20 adults that participated in the Plyler et al (2007) experiment agreed to participate in the present experiment. All participants had 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 [American National Standards Institute, 1996]), had normal tympanograms bilaterally, and were current binaural hearing instrument users (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 [American National Standards Institute, 1991]).

Hearing Instruments and Fitting

Each hearing instrument used was the same digital in-the-ear device with four-channel WDRC processing and multiple memory capability (Starkey Axent II) used in the Plyler et al (2007) experiment. Each hearing instrument was previously programmed using the NAL-NL1 fitting strategy (Byrne et al, 2001). The compression parameters were determined by the Starkey software and varied across participants based on their audiometric data and resulting in-situ targets. The expansion parameters were also determined by the Starkey software but were constant across all hearing instruments (Figure 2). Three memories of each hearing instrument were programmed in a random order such that expansion was activated in channel one only (<750 Hz) and in channels one and two only (<1750 Hz) and deactivated in all four channels (Off) across memories; however, participants were unaware of which expansion condition they were using at all times. All other fittings parameters were identical across the three memories, and the noise suppression feature and volume control were deactivated for the experiment.

Probe-microphone measures were conducted on each ear using pink noise at 50, 65, and 80 dB SPL to verify match to NAL-NL1 targets (Byrne et al, 2001) (±6 dB from 500-4000 Hz) and with the loudspeaker deactivated to verify appropriate functioning of the expansion feature (Mueller, 2001). All probe-microphone measurements were downloaded to a personal computer and were averaged across 26 ears for 13 of the 15 participants (note: data from two participants were excluded due to an equipment malfunction). Probe-microphone measures obtained with the loudspeaker deactivated revealed a mean in-situ level of 28 dB SPL for the unaided condition, 38 dB SPL for the Channels 1 and 2 condition, 41 dB SPL for the Channel 1 condition, and 44 dB SPL for the Off condition averaged over the frequency range of 200 to 2000 Hz (Figure 3).

Objective Evaluation

Objective evaluations were conducted in quiet using the CST and in noise using the HINT (see Plyler et al, 2007, for review). The CST is normally conducted using a fixed signal-to-noise ratio (SNR); however, no background noise was utilized in order to evaluate the effects of low-frequency expansion in a quiet setting. The HINT protocol utilized reflected a slight modification of the original HINT protocol in that noise levels were varied and speech levels were fixed. This modification ensured consistent speech levels between the CST and the HINT stimuli. 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 at 0° azimuth in the sound-treated examination room (Industrial Acoustic). Participants were seated 1m from the loudspeaker, and the CST and the HINT were administered at 40 dB SPL (peak) for the three expansion conditions (Off, Channel 1, Channels 1 and 2). Two CST and two HINT trials were conducted for each expansion condition, and an average of the two trials

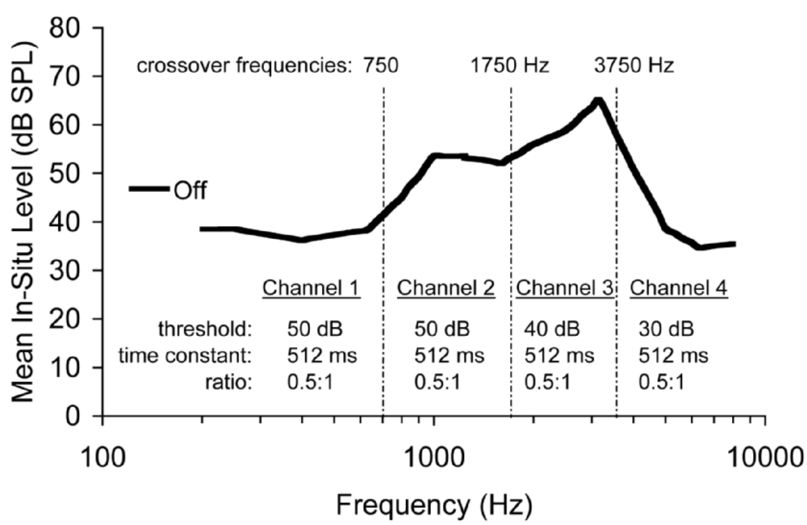

Figure 2. Expansion parameters determined by the Starkey software and crossover frequencies between the first and second, second and third, and third and fourth channels of each hearing instrument. Mean in-situ levels averaged across ears for 13 of the 15 participants for the expansion off condition are shown for reference purposes.

served as the CST or HINT score for that participant in the given condition. Prior to data collection, an experimental schedule was generated listing a completely randomized assignment for expansion condition, CST passage, and HINT sentence list for each participant.

Subjective Evaluation

In previous expansion studies, subjective evaluations were conducted in the participants' own homes instead of in the laboratory to examine expansion in the real-world settings for which it was designed (Plyler et al, 2005a; Plyler et al, 2006; Plyler et al, 2007). In the present study, subjective evaluations were conducted in laboratory to determine if laboratory findings agree with those obtained in more real-world listening environments. All participants were asked to rate their satisfaction for each memory under two listening conditions while seated in a sound-treated examination room: (1) in quiet, and (2) while listening to CST sentences (Cox et al, 1987) presented at 40 dB SPL (peak). The presentation level of 40 dB SPL ensured the activation of expansion for those memories in which expansion could be activated. For each expansion condition, participants were asked to rate their satisfaction regarding the amount of background-noise reduction they perceived in quiet (i.e., listening to the ambient noise in the examination room) and when listening to low-level speech using a five-point scale (1=unsatisfied, 2=somewhat satisfied, 3=satisfied, 4=very satisfied, 5=extremely satisfied) (Appendix). Two evaluation sessions were conducted for each listening condition for each participant. Prior to data collection, an experimental schedule was generated for each participant listing a completely randomized assignment for listening condition, expansion condition, and CST passage. At the completion of the experiment, each participant was asked to indicate which setting they preferred overall to determine if low-frequency expansion affected overall preference.

RESULTS

Objective Evaluation

Prior to statistical analysis, individual percent-correct scores were converted to rationalized arcsine transform units (raus) to stabilize error variance (Studebaker, 1985). Connected Speech Test scores and HINT SNRs were averaged within participants for each expansion condition (Figures 4 and 5 respectively). Two one-way repeated measures analyses of variance were performed to evaluate the effects of low-frequency expansion on speech recognition in quiet

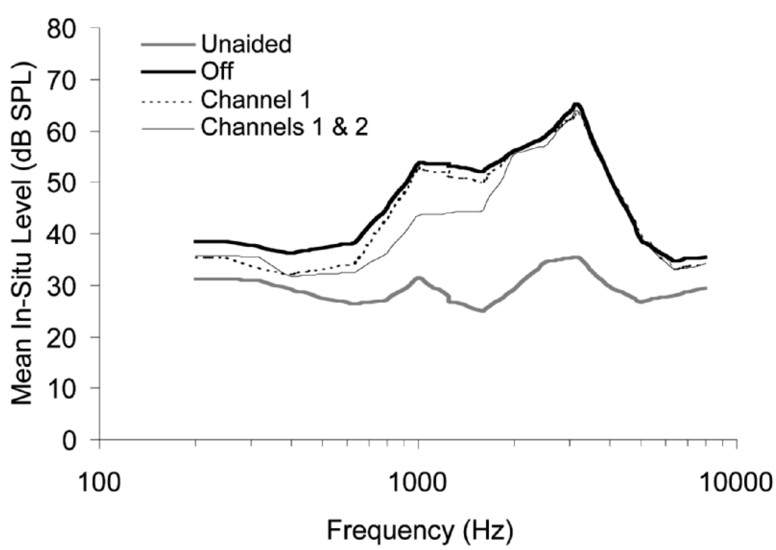

Figure 3. Mean in-situ levels averaged across ears for 13 of the 15 participants for each expansion condition and the unaided condition with the loudspeaker deactivated.

Table 1. Comparisons from the CST and HINT Data Controlling for Familywise Error Rate across the Tests at the 0.05 Level, Using the Holm's Sequential Bonferroni Procedure within Condition

Test	Pair	Mean Difference	Standard Deviation	t (14)	Adjusted p Value
CST	Off, Channel 1	3.73	16.17	0.89	0.386
	Off, Channels 1 & 2	14.33	21.59	2.57	0.004
	Channel 1, Channels 1 & 2	10.60	14.87	2.76	0.045
HINT	Off, Channel 1	1.00	4.09	0.95	0.359
	Off, Channels 1 & 2	-4.80	6.32	-2.94	0.022
	Channel 1, Channels 1 & 2	-5.80	6.60	-3.40	0.001

and in noise. The dependent variable was CST score for one analysis and HINT SNR for the other analysis. For each analysis, the within-subject factor was expansion with three levels (Off, Channel 1, Channels 1 and 2). A significant expansion effect was revealed for the CST [$F(2,28) = 5.246$, $p<0.05$, partial $\eta^2 = 0.273$, $\Omega = 0.790$] and for the HINT [$F(1,14) = 8.644$, $p<0.05$, partial $\eta^2 = 0.382$, $\Omega = 0.780$] results. Paired samples t-tests were conducted to further investigate each expansion main effect controlling for familywise error rate across the tests at the 0.05 level, using the Holm's sequential Bonferroni procedure. Results indicated that CST scores and HINT SNRs were significantly poorer for the Channels 1 and 2 condition than for the Channel 1 or Off conditions; however, CST scores and HINT SNRs were not significantly different between the Channel 1 and Off conditions (Table 1).

Subjective Evaluation

Satisfaction Ratings

Individual satisfaction ratings were completed by all participants and were averaged across two trials for each expansion condition and each listening environment (Figure 6). Two one-way repeated measures analyses of variance were performed to evaluate the effects of low-frequency expansion on listener satisfaction ratings in quiet and when listening to low-level speech. The dependent variable was mean satisfaction rating, and the within-subject factor was expansion with three levels (Off, Channel 1, Channels 1 and 2) for each analysis. A significant expansion effect was revealed for the quiet [$F(2,28) = 5.589$, $p<0.05$, partial $\eta^2 = 0.285$, $\Omega = 0.816$] and for the low-level speech [$F(2,28) = 7.408$, $p<0.05$, partial $\eta^2 = 0.346$, $\Omega = 0.914$] ratings results. Paired sam-

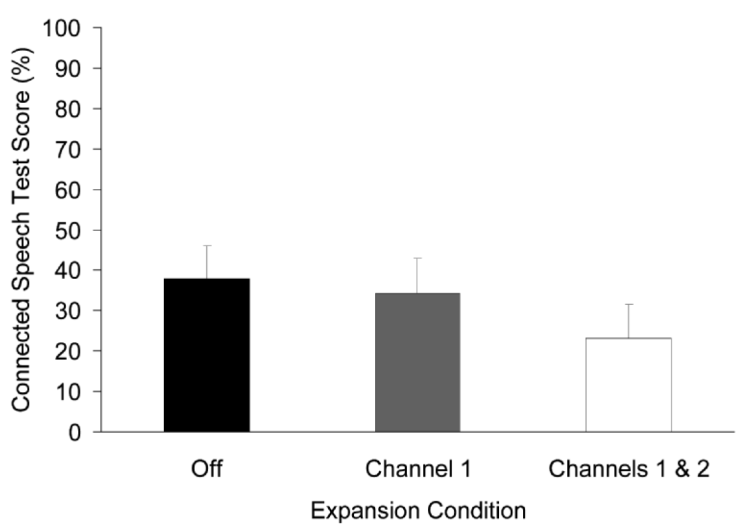

Figure 4. Mean CST in quiet scores and standard deviations for participants at 40 dB SPL for each expansion condition.

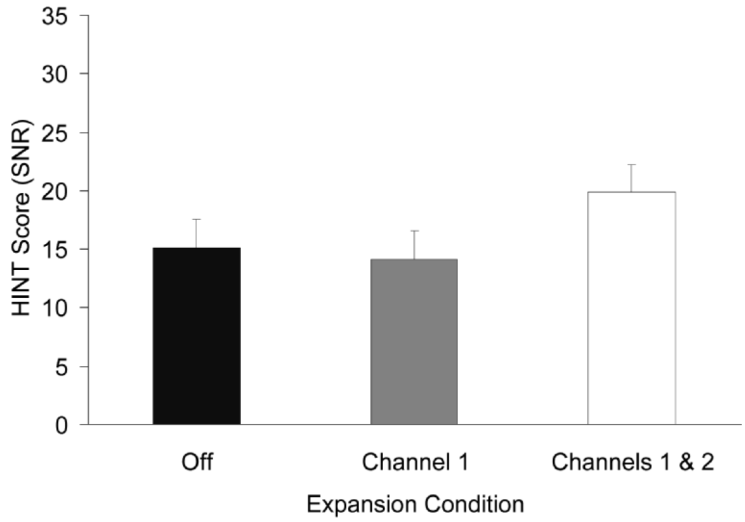

Figure 5. Mean HINT SNRs and standard deviations for participants at 40 dB SPL for each expansion condition.

ples t-tests were conducted to further investigate each expansion main effect controlling for familywise error rate across the tests at the 0.05 level, using the Holm's sequential Bonferroni procedure. Results in quiet indicated that satisfaction ratings were significantly lower for the Off condition than for the Channels 1 and 2 condition; however, satisfaction ratings for the Channel 1 condition were not significantly different from ratings for the Off or the Channels 1 and 2 conditions (Table 2). Conversely, low-level speech results indicated that satisfaction ratings were significantly higher for the Off and Channel 1 conditions than for the Channels 1 and 2 condition; however, satisfaction ratings for the Off condition were not significantly different from ratings for the Channel 1 condition (Table 2). These results indicated that the effects of expansion on listener satisfaction ratings depend on the listening environment.

Overall Preference

Overall preference results were obtained from the 15 participants and are displayed in Figure 7. A one-sample chi-square test was conducted to determine whether listeners had a preferred expansion condition (Off, Channel 1, Channels 1 and 2) (note: the exact option was used to determine significance due to the small sample size). The result of the test was significant, $\chi^2(1, N = 15) = 8.40$, $p<0.05$. The proportion of listeners that preferred the Channel 1 condition ($\underline{P} = 0.66$) was greater than the hypothesized proportion of 0.33 while the proportion of listeners that preferred the Off ($\underline{P} = 0.26$) and Channels 1 and 2 conditions ($\underline{P} = 0.06$) was less than the hypothesized proportion of 0.33. Follow-up testing indicated that the proportion of listeners preferring the Channel 1 condition differed significantly from the proportion of listeners preferring the Channels 1 and 2 condition,

Table 2. Comparisons from the Satisfaction Ratings Data Controlling for Familywise Error Rate across the Tests at the 0.05 Level, Using the Holm's Sequential Bonferroni Procedure within Condition

Environment	Pair	Mean Difference	Standard Deviation	t (14)	Adjusted p Value
Quiet	Off, Channel 1	-0.93	1.58	-2.29	0.076
	Off, Channels 1 & 2	-1.23	1.72	-2.78	0.045
	Channel 1, Channels 1 & 2	-0.30	1.10	-1.06	0.308
Low-Level Speech	Off, Channel 1	0.20	0.10	0.78	0.450
	Off, Channels 1 & 2	1.20	1.37	3.38	0.012
	Channel 1, Channels 1 & 2	1.00	1.46	2.65	0.038

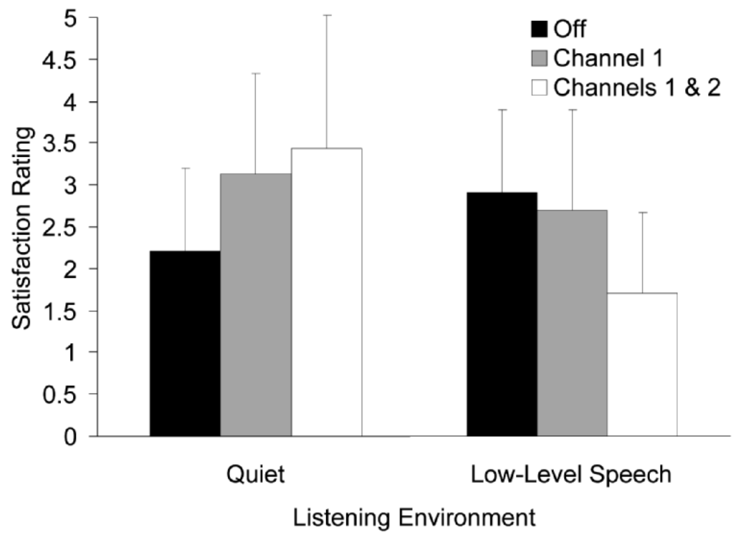

Figure 6. Mean satisfaction ratings and standard deviations for participants when listening in quiet and when listening to low-level speech (CST sentences) in the sound treated booth for each expansion condition using a five-point scale (1=unsatisfied, 2=somewhat unsatisfied, 3=satisfied, 4=very satisfied, 5=extremely satisfied).

$\chi^2(1, N = 11) = 0.007$, $p<0.05$; however, the proportion of listeners preferring the Channel 1 condition did not differ significantly from the proportion of listeners preferring the Off condition, $\chi^2(1, N = 14) = 0.109$, $p>0.05$. These results suggested that listeners preferred expansion in Channel 1 only to expansion in Channels 1 and 2; however, overall preference was not significantly different between the Channel 1 and Off conditions.

DISCUSSION

Objective Evaluation

One purpose of the present study was to determine if low-frequency expansion affected the recognition of low-level speech in quiet and in noise. Results were in agreement with previous findings obtained using multi-channel expansion

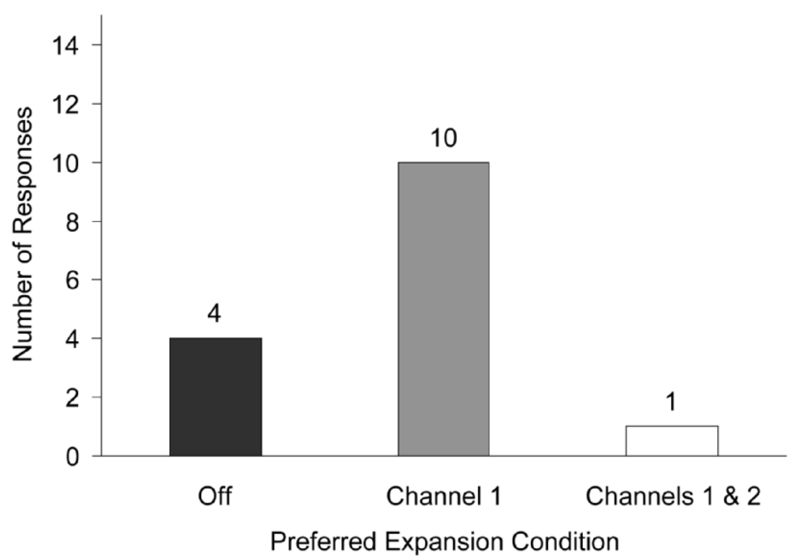

Figure 7. Overall preference results for participants when listening in quiet and when listening to low-level speech (CST sentences) for each expansion condition.

in that multi-channel expansion restricted to 2000 Hz significantly degraded objective performance in quiet and in noise relative to the Off condition, presumably due to reduced audibility of speech cues necessary for accurate feature identification during expansion activation (Plyler et al, 2005a; Plyler et al, 2007). Results further indicate, however, that restricting expansion to lower frequency regions than those examined by Plyler et al (2007) did not significantly degrade the recognition of low-level speech in quiet and in noise.

Audibility of low-level speech cues may explain the speech-recognition patterns observed in the present examination of low-frequency expansion. Probe-microphone measures revealed that in-situ levels decreased by an average of 7.3 dB from 1000 to 2000 Hz for the Channels 1 and 2 condition relative to the Off condition (Figure 3). Conversely, in-situ levels decreased by an average of 1.4 dB from 1000 to 2000 Hz for the Channel 1 condition relative to the Off condition (Figure 3). As a result, the audibility of speech cues necessary for accurate feature identification may have been significantly reduced for the Channels 1 and 2 condition relative to the Off condition; however, audibility of necessary speech cues may have been similar between the Channel 1 and Off conditions. Therefore, findings of the current investigation suggest that limiting expansion activation to 1000 Hz and below does not result in significant speech-recognition deficits observed when expansion is active across a broader spectrum, possibly due to improved audibility of necessary speech cues between 1000 and 2000 Hz (Figure 3).

Subjective Evaluation

Quiet

A second purpose of the present study was to determine if low-frequency expansion affected satisfaction with low-level noise reduction. Satisfaction ratings with low-frequency expansion were evaluated in quiet and in the presence of low-level speech. Results indicated that satisfaction with low-frequency expansion was dependent on the listening environment. In quiet, listener satisfaction ratings were significantly greater for the Channels 1 and 2 condition than the Off condition. This result was in agreement with previous findings obtained using multi-channel expansion in real-world settings in that multi-channel expansion activated in Channels 1 and 2 significantly improved satisfaction ratings in quiet relative to the Off condition, presumably due to reduced audibility of low-level environmental noises as well as noises generated by the hearing instrument (Plyler et al, 2007).

Results in quiet further indicated that listener satisfaction ratings were similar between the Channel 1 condition and both the Channels 1 and 2 and Off conditions. This outcome seemed paradoxical at first glance. On one hand, limiting expansion to Channel 1 maintains subjective benefit observed when expansion is active in Channels 1 and 2 or across the entire spectrum (Plyler et al, 2007). On the other hand, limiting expansion to Channel 1 does not provide significantly greater subjective benefit than the Off condition. This result was not expected and is difficult to interpret. Although satisfaction ratings appeared greater for the Channel 1 condition than for the Off condition, ratings differences approached but did not reach statistical significance ($p = 0.07$). It should be noted, however, that statistical significance is reached between the conditions if adjustments for multiple comparisons are not made, thereby suggesting that satisfaction ratings may be significantly greater when expansion is limited to 1000 Hz and below (Channel 1) than when expansion is deactivated when listening in a quiet environment. Nonetheless, listener satisfaction ratings between these two conditions (Channel 1 and Off) did not differ significantly in quiet and warrants further study in the future.

Low-Level Speech

Results obtained when listening to low-level speech indicated that listener satisfaction ratings were significantly reduced when expansion was activated in Channels 1 and 2; however, satisfaction ratings were significantly improved when expansion was limited to Channel 1 or deactivated. These results were not in agreement with previous findings obtained when listening in low-level environments using either single-channel or multi-channel expansion which indicated that any form of expansion significantly improved listener satisfaction ratings in everyday environments despite the fact expansion significantly reduced speech-recognition in quiet and in noise (Plyler et al, 2005a; Plyler et al, 2007).

Differences in listener satisfaction ratings in low-level environments observed between the present and previous research could be attributed to the methodological differences used between investigations. In previous research, participants evaluated each expansion condition in their own homes instead of in the laboratory in order to examine the effects of expansion in the real-world settings for which expansion was designed (Plyler et al, 2005a; Plyler et al, 2007; Plyler et al, 2006). Participants were instructed to conduct their everyday 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, etc. (Plyler et al, 2005a; Plyler et al, 2007; Plyler et al, 2006). Consequently, it is possible some participants did not listen to speech when evaluating expansion in their everyday environment while others rarely listened to speech at such low levels. In either case, speech-recognition deficits from expansion activation would have gone unnoticed and would not impact the subjective results. Conversely, it is also possible that the noise-reduction benefits produced by expansion outweighed the speech-recognition deficits produced when listening in a low-level environment given the fact most listeners preferred the use of expansion (Plyler et al, 2005a; Plyler et al, 2007; Plyler et al, 2006).

In the present study, subjective evaluations were conducted in laboratory to determine if laboratory findings agreed with those obtained in more real-world environments. Each participant was asked to rate his or her satisfaction with each expansion condition when listening in quiet and when listening to low-level speech (40 dB SPL) while seated in a sound-treated examination room. This design ensured that (1) ambient levels fell below the expansion thresholds and engaged the feature during quiet evaluations (Figure 3) and (2) participants actually listened to low-level speech when evaluating each expansion condition. Interestingly, satisfaction ratings results obtained when listening to low-level speech were in agreement with objective results in that performance for both measures was significantly reduced when expansion was activated in Channels 1 and 2 while performance improved significantly when expansion was limited to Channel 1 or was deactivated. Therefore, these results suggest that satisfaction with expansion depends on the listening environment of the end user. Results further indicate, however, that limiting expansion activation to 1000 Hz and below (Channel 1) does not significantly reduce expansion satisfaction when listening in quiet or when listening to low-level speech.

Overall Preference

The final purpose of the present study was to determine if low-frequency expansion affected overall listener preference. A significant number of participants preferred limiting expansion activation to Channel 1 (66.6%) to activating expansion in Channels 1 and 2 (6.6%); however, the number of participants who preferred no expansion (26.6%) was not significantly different from the number of participants who preferred limiting expansion activation to Channel 1 (66.6%). This result was not in complete agreement with previous research (Plyler et al, 2005a; Plyler et al, 2007), which indicated that listeners preferred any form of expansion to no expansion. However, overall preference differences observed between the present and previous research could be attributed to the methodological differences between investigations. In the present research, satisfaction ratings were conducted in the laboratory and were affected by the listening environment, thereby potentially affecting the overall preference results.

Furthermore, preference results were also in agreement with low-level speech satisfaction ratings and objective results. For example, 93% of the participants preferred deactivating expansion or limiting expansion activation to Channel 1, conditions which maximized speech recognition in quiet, speech recognition in noise, and satisfaction ratings when listening to low-level speech. Therefore, results of the present study suggest limiting expansion activation to 1000 Hz and below (Channel 1) preserves both objective and subjective performance in quiet and in low-level environments, and is preferred overall by a significant number of participants.

CONCLUSIONS

Results of the present study indicate that hearing-instrument users prefer the use of low-frequency expansion to expansion that affects a larger frequency spectrum. Results further suggest that restricting expansion to below 1000 Hz overcomes speech-recognition deficits observed when expansion is active across a broader spectrum (Plyler et al, 2005a; Plyler et al, 2007) without significantly reducing subjective benefit for WDRC hearing-instrument users. Dispensers should be aware that subjective performance with expansion depends on whether the end user is listening in a quiet environment or is listening to low-level speech. Lastly, any interpretation of results should consider the specific expansion parameters used in this study. Because the effect of expansion on low-level speech and noise depends on the expansion parameters, these results may not generalize to other types of expansion systems (e.g., more than four channels or other expansion parameters such as threshold, ratio and time constant). Future work should investigate the role these parameters play on the effectiveness of expansion.

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Appendix

Initials: ___________________ Date: _______________________

Quiet	Rate your satisfaction with the amount of background noise reduction (1=unsatisfied, 2=somewhat satisfied, 3=satisfied, 4=very satisfied, 5=extremely satisfied)	Speech	Rate your satisfaction with the amount of background noise reduction (1=unsatisfied, 2=somewhat satisfied, 3=satisfied, 4=very satisfied, 5=extremely satisfied)
Evaluation Session 1:	Memory 1:_____ Memory 2:_____ Memory 3:_____ Favorite:______		Memory 1:_____ Memory 2:_____ Memory 3:_____ Favorite:______
Evaluation Session 2:	Memory 1:_____ Memory 2:_____ Memory 3:_____ Favorite:______		Memory 1:_____ Memory 2:_____ Memory 3:_____ Favorite:______

Comments: ____

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