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Limiting High-Frequency Hearing Aid Gain in Listeners with and without Suspected Cochlear Dead Regions

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Abstract

The purpose of this study was to compare threshold-matched ears with and without suspected cochlear dead regions in terms of the speech perception benefit from high-frequency amplification. The Threshold Equalizing Noise Test (TEN) was used to assess the presence of dead regions. Speech perception was measured while participants were wearing a hearing aid fit to approximate DSL[i/o] targets. Consonant identification of nonsense vowel-consonant-vowel combinations was measured in quiet using a forced-choice procedure. Phoneme recognition was measured at signal-to-noise ratios ranging from 0 to +15 dB using the Computer-Assisted Speech Perception Assessment test (CASPA). Recognition scores were obtained for unfiltered stimuli and stimuli that were low-pass filtered at the estimated boundary of the suspected dead regions, ½ octave above and 1 octave above the boundary. Filter settings for the ears without suspected dead regions were the same as settings of the threshold-matched counterpart.

In quiet and in low levels of noise, speech perception scores were significantly higher for the wide-band (unfiltered) condition than for the filtered conditions, and performance was similar for the ears with and without suspected dead regions. In high levels of noise, mean scores were highest in the wide-band condition for the ears without suspected dead regions, but performance reached an asymptote for the ears with suspected dead regions. These results suggest that patients with cochlear dead regions may experience speech perception benefit from wide-band high-frequency gain in quiet and low levels of noise, but not in high levels of noise.

Key Words: Cochlear dead regions, hearing amplification, speech perception

Abbreviations: CASPA = Computer-Assisted Speech Perception Assessment; TEN =threshold equalizing noise; VCV=vowel-consonant-vowel

Sumario

El propósito de este estudio fue comparar oídos ordenados por umbral, con y sin la sospecha de poseer regiones cocleares muertas, analizados en términos del beneficio de la amplificación en las altas frecuencias para la percepción del lenguaje. Se utilizó la Prueba de Ruido Ecualizador del Umbral (TEN) para evaluar la presencia de regiones muertas. La percepción del lenguaje fue evaluada mientras los participantes estaban utilizando auxiliares auditivos graduados para acercarse a las metas DSL[i/o]. La identificación

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de consonantes en combinaciones vocal-consonante-vocal sin sentido, se midió en silencio usando un procedimiento de escogencia forzada. El reconocimiento de fonemas fue medido con tasas de señal/ruido desde 0 a +15 dB, usando la prueba de Evaluación de la Percepción del Lenguaje Asistida por Computadora (CASPA). Los puntajes de reconocimiento fueron obtenidos para estímulos no filtrados y estímulos que fueron filtrados con filtros de pasa-bajo, en el límite estimado de las regiones sospechosas de estar muertas, media octava por encima y por debajo de dicho límite. El establecimiento de los filtros para los oídos sin áreas muertas fue igual al de las contrapartes ordenadas por umbral.

En silencio y en niveles bajos de ruido, los puntajes de la percepción del lenguaje fueron significativamente más altos para las condiciones de banda ancha (no filtradas) que para las filtradas, y el rendimiento fue similar para los oídos con y sin regiones sospechosas de estar muertas. A niveles elevados de ruido, los puntajes medios en la condición de banda ancha fueron los más altos para aquellos oídos sin áreas muertas, pero el rendimiento alcanzó una asíntota para los oídos con regiones sospechosas de estar muertas. Estos resultados sugieren que los pacientes con áreas cocleares muertas pueden experimentar un beneficio en la percepción del lenguaje a partir de una ganancia de banda ancha y alta frecuencia, en silencio y a niveles bajos de ruido, pero no en medio de niveles elevados de ruido.

Palabras Clave: Región coclear muerta, amplificación auditiva, percepción del lenguaje

Abreviaturas: CASPA = Evaluación de la Percepción del Lenguaje Asistida por Computadora; TEN = ruido ecualizador del umbral; VCV = vocal-consonante-vocal

Individuals with high-frequency hearing loss have difficulty with speech understanding largely because of reduced audibility of high-frequency speech cues. A general goal of amplification is to restore audibility of high-frequency speech information. Several investigators have shown, however, that not all listeners with high-frequency hearing loss can make efficient use of these cues (e.g., Ching et al, 1998; Hogan and Turner, 1998). These investigators observed that the efficiency with which listeners with high-frequency hearing losses used audible high-frequency information decreased with increasing hearing loss. Hogan and Turner reported that the contribution of high-frequency information to speech recognition was less than that of normal-hearing listeners once thresholds exceeded 55 dB HL. In both studies, the majority of listeners with 4 kHz thresholds of 80 dB HL or higher were unable to make use of audible high-frequency information, and some listeners showed a decrease in speech intelligibility when this information was made audible. A notable characteristic of both studies was the substantial intersubject variability in the contribution of high-frequency information to speech intelligibility, particularly for thresholds between 60 and 80 dB HL in the 2000–8000 Hz range. In this range, high-frequency information made a substantial contribution to speech understanding for some subjects, while others with similar thresholds did not benefit from high-frequency information, and some experienced deterioration in speech intelligibility.

Individual differences in the ability to use high-frequency speech information may arise from individual differences in the pattern of damage to the auditory system. It has been suggested that extensive damage to the inner hair cells may account for the reduced benefit from high-frequency amplification in some individuals with steeply sloping hearing loss (Hogan and Turner, 1998). These regions of extensive inner hair cell loss have been referred to as "cochlear dead regions" (Moore et al, 2000). Although cochlear dead regions are generally associated with severe steeply sloping hearing loss, dead regions cannot be accurately identified from audiometric characteristics alone (Moore et al, 2000; Summers et al, 2003). Psychophysical tuning curves and, more recently, the Threshold Equalizing Noise Test (TEN) have been used to identify cochlear dead regions (Moore et al, 2000). The TEN Test involves the measurement of pure-tone thresholds in the presence of broadband noise spectrally shaped so as to produce equal masked thresholds across frequencies. Dead regions at specific frequencies are indicated by elevated thresholds in the presence of this masking noise (Moore et al, 2000; Moore, 2001).

There has been increasing interest regarding the extent to which patients with dead regions can benefit from high-frequency amplification. Vickers et al (2001) and Baer et al (2002) examined the effects of varying the extent of high-frequency amplification on consonant recognition in listeners with and without high-frequency dead regions. Speech was delivered under headphones after applying spectrally shaped amplification based on the Cambridge fitting formula (Moore and Glasberg, 1998). Stimuli were low-pass filtered at various cutoff frequencies to produce different amounts of high-frequency amplification. Under quiet listening conditions, consonant recognition by listeners with dead regions improved with low-pass filter cutoffs up to 50–100% above the estimated edge of the dead regions. However, when higher frequencies were included, performance generally reached an asymptote or deteriorated. In contrast, listeners without dead regions continued to show improvement in consonant recognition when more high-frequency information was included. A similar pattern was observed when listeners were tested in background noise with signal-to-noise ratios ranging from 0–6 dB (Baer et al, 2002).

The studies described above suggest that listeners with cochlear dead regions receive less benefit from wide-band amplification than listeners without cochlear dead regions. It is important to note, however, that the listeners with dead regions in these studies also had more severe hearing losses than listeners without dead regions. Apart from the presence of dead regions, it is unclear how these threshold differences might have influenced the results. From a clinical perspective, it is unclear whether the information about cochlear dead regions would have provided any clinically relevant information beyond that provided by the audiogram. Most of the high-frequency (4 kHz) thresholds of the listeners with dead regions exceeded the 80 dB HL level that is generally associated with the absence of high-frequency contribution to speech intelligibility in listeners with steeply sloping high-frequency hearing loss (Ching et al, 1998).

The purpose of the present study was to

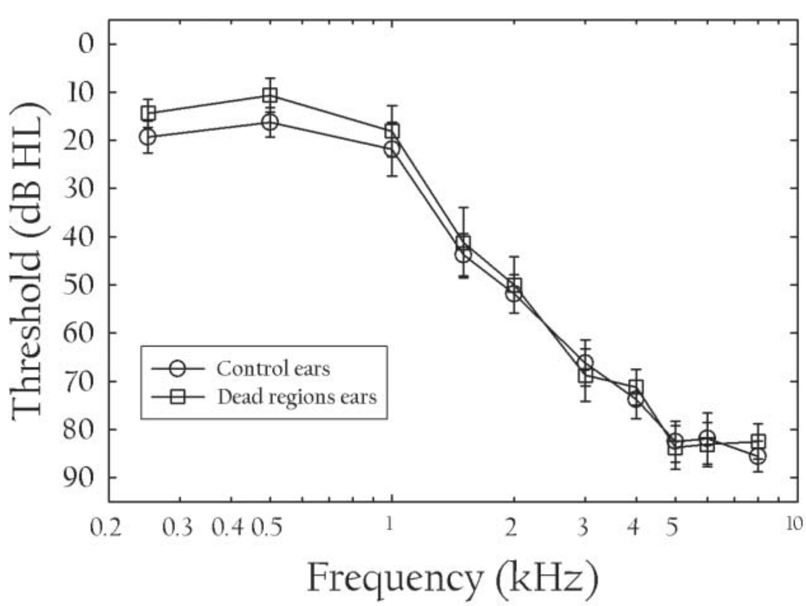

Figure 1. Mean pure-tone thresholds +/-1 standard error for control ears without dead regions and ears with suspected dead regions.

compare speech recognition benefit from high-frequency amplification in listeners with and without suspected cochlear dead regions who have similar audiometric thresholds. Participants with suspected dead regions in the present study generally had less hearing loss than listeners in previous studies. In addition, the majority of participants selected for the present study had hearing losses similar to those shown to exhibit the greatest range of variability in benefit from high-frequency amplification in previous studies.

METHOD

Participants

Fourteen adults with steeply sloping high-frequency hearing loss participated in the study. In total, eight ears with suspected dead regions and eight ears without dead regions were tested. Evidence of dead regions was based on results from the TEN Test (Moore et al, 2000). Two participants had evidence of dead regions in both ears. For these two participants, testing was done separately for each ear. Eight control ears (without suspected dead regions) were selected from a database of 53 ears with normal TEN Test results and steeply sloping high-frequency hearing losses. The ears without suspected dead regions were selected to match the thresholds of one of the eight ears with suspected dead regions as closely as possible. Mean pure-tone air-conduction thresholds for the ears tested are shown in Figure 1, and audiometric thresholds for individual ears are shown in Table 1.

Table 1. Individual Pure-Tone Thresholds 250–8000 Hz (dB HL) for Control Ears without Dead Regions (C) and Ears with Suspected Dead Regions (DR) and Differences between Thresholds for Matched Pairs (e.g., 1DR-1C)

	250	500	1000	1500	2000	3000	4000	6000	8000	rms of Difference
1C	15	5	20	55	55	65	70	70	75	
1DR	15	10	20	45	45	55	65	70	75	
1DR-1C	0	5	0	-10	-10	-10	-5	0	0	6.2
2C	10	15	30	50	55	60	75	70	85	
2DR	15	5	15	50	55	60	65	75	80	
2DR-C	5	-10	-15	0	0	0	-10	5	-5	7.5
3C	25	10	10	30	40	55	75	80	80	
3DR	0	0	0	15	45	75	80	80	80	
3DR-3C	-25	-10	-10	-15	5	20	5	0	0	12.9
4C	15	5	5	25	35	70	80	85	85	
4DR	5	-5	-5	10	20	65	70	80	75	
4DR-4C	-10	-10	-10	-15	-15	-5	-10	-5	-10	10.5
5C	30	20	10	35	45	50	50	60	75	
5DR	20	15	20	30	45	55	55	70	70	
5DR-5C	-10	-5	10	-5	0	5	5	10	-5	6.9
6C	5	25	55	60	55	65	75	95	90	
6DR	15	20	40	55	55	80	75	105	100	
6DR-6C	10	-5	-15	-5	0	15	0	10	10	9.4
7C	30	25	20	50	60	70	75	90	95	
7DR	20	20	30	60	55	60	70	85	85	
7DR-7C	-10	-5	10	10	-5	-10	-5	-5	-10	8.2
8C	25	25	25	45	70	95	90	105	100	
8DR	25	20	25	65	80	100	90	100	95	
8DR-8C	0	-5	0	20	10	5	0	-5	-5	8.2

Note: The root-mean-square (rms) of the threshold differences for each matched pair is shown in the right column.

Threshold Equalizing Noise (TEN) Test

The TEN test was administered using the procedures recommended by Moore et al (2000). All testing was completed in a double-walled IAC sound booth. TEN Test stimuli were played from a compact disc routed to a two-channel audiometer (Grason-Stadler 16) and delivered monaurally to TDH-59 earphones. Thresholds for 250, 500, 1000, 1500, 2000, 3000, 4000, 5000, 6000, and 8000 Hz pure tones were to be determined using a standard clinical bracketing procedure with a minimum step size of 5 dB. Participants were asked to push a button when they detected a tone. Thresholds were first determined in quiet, then in the presence of the threshold-equalizing noise at the level of 70 dB/equivalent rectangular bandwidth (ERB).

The presence of cochlear dead regions was determined using the criteria recommended by Moore et al (2000) in the validation study of the test. A masked threshold that was at least 10 dB above the absolute threshold and at least 10 dB above the level/ERB of the threshold-equalizing noise was taken as evidence of a dead region at the specific frequency tested.

All of the ears with suspected dead regions in the current study had abnormal TEN Test results at three or more contiguous frequencies. In the present study, the presence of dead regions was not confirmed with psychophysical tuning curves. False-positive results have been reported with the TEN Test, but these results occur primarily in cases in which the TEN Test indicates abnormalities in one or two isolated frequencies surrounded by normal TEN results on either side (Moore et al, 2000; Summers et al, 2003).

The boundary of the dead region was estimated as the lowest frequency at which an abnormal TEN Test result was obtained. The ears tested in this study had dead region boundaries of either 2000 or 3000 Hz. Four ears had estimated dead region boundaries at 2000 Hz, and the remaining four ears had boundaries at 3000 Hz. Other potential participants with dead regions starting at higher or lower frequencies were not included for several reasons. First, it would not have been possible to amplify the higher frequencies effectively with the wearable aid used in the study. In addition, it was difficult to find participants without dead regions whose thresholds were similar to ears with lower dead region boundaries because the lower boundaries are associated with considerably greater hearing loss.

Hearing Aid Programming and Verification

All participants were tested with a behind-the-ear digital hearing aid coupled to a custom soft-shell unvented earmold fitted with a 4 mm Libby horn. The digital hearing aid was programmed to approximate gain prescribed by DSL[i/o] (Cornelisse et al, 1995). This prescription was chosen in order to maximize high-frequency gain. Digital feedback management (notch filter) and noise reduction were disabled for the entire experiment, including verification.

Frequency responses were verified using real-ear measures. Real-ear aided responses were measured using the dynamic speech-weighted signal on the Audioscan RM500. Adjustments to the gain were made to match the DSL[i/o] targets as closely as possible. Mean ear canal sound pressure levels for the same input were within 5 dB for the two groups through 6300 Hz.

Filtering Conditions

The amount of high-frequency energy available to the listener was manipulated by low-pass filtering the speech stimuli at different cutoff frequencies. The filter cutoff conditions for each subject were determined based on the estimated boundary of the dead regions. In each case, stimuli were filtered at the estimated dead region boundary, ½ octave above the boundary, and 1 octave above the boundary. For example, a subject whose estimated dead regions boundary was 2000 Hz would hear stimuli low-pass filtered with cutoffs at 2000 Hz (at the boundary), 2828 Hz (½ octave above), and 4000 Hz (1 octave above the boundary). Filter cutoff frequencies for the control ears were identical to those of the matched members of the dead regions group.

Digital filter coefficients were created using the DADISP FIR module (DADISP, 1996), and filtering was implemented using a Tucker-Davis Technologies programmable filter (TDTII PA4). Filter slopes were 60 dB/octave, and cutoff frequencies were 2000, 2828, 4000, and 5656 Hz.

Speech Perception Testing

All testing took place in a double-walled sound booth. Speech perception tests were administered unfiltered and under the three filtering conditions described above. Testing took place over two sessions, and each of the two speech perception tests were administered in both sessions. The order of the filtering conditions was counterbalanced across subjects and sessions.

Stimuli for both speech perception tests were played through a Creative-Labs SB-16 Sound Card at the rate of 22.05k samples/sec with 16-bit resolution. The output of the sound card was routed to the tape input of a Grason-Stadler GSI-16 audiometer and delivered to a loudspeaker positioned one meter directly in front of the listener. Continuous speech-shaped noise was delivered to the unaided ear through an insert earphone at a level of 55 dB SPL during the testing.

Consonant Identification in Quiet

Stimuli used to assess consonant identification in quiet consisted of vowel-consonant-vowel (VCV) combinations constructed by combining three vowels (/a/, /i/, /u/) with seven consonants /t/, /p/, /k/, /θ/, /ʃ/, /f/, /s/. Each of the three subtests consisted of seven stimuli: one vowel paired with each consonant and an additional stimulus with the consonant removed (e.g., /a/_/a/). These stimuli were chosen because accurate identification requires access to high-frequency cues. Five tokens of each combination were digitally recorded by a female talker using 16-bit resolution and a sampling rate of 22.05 kHz. Files were equalized to the same overall rms level.

The VCV stimuli were presented in quiet at an average rms level of 65 dB SPL, as measured in the unfiltered condition. No adjustments were made to overall level for the filtered conditions. During each subtest, eight alternatives (seven VCV combinations and one vowel alone) appeared on the computer monitor (e.g., "ah-ah," "ah-pah," etc.). During each trial the subject heard one of the VCV combinations. The subject was instructed to select the stimulus he/she heard using the computer mouse. No feedback was provided. A practice session consisting of one administration of each subtest was provided during each test session. Excluding practice, each subtest was presented four times under each condition.

Computer-Assisted Speech Perception Assessment Test (CASPA)

The CASPA materials consist of 20 digitized monosyllabic word lists, recorded by a female talker (Mackersie et al, 2001). The ten-word lists consist of vowel-consonant-vowel words with one example of each of the same 30 phonemes in each list. The test was administered via the computer. Phoneme scoring was completed interactively with computer assistance.

Speech stimuli in the CASPA Test were administered at 65 dB SPL (average vowel peaks) as measured in the unfiltered condition. No adjustments were made to overall level for the filtered conditions. Phoneme recognition was measured in the presence of spectrally matched noise at signal-to-noise ratios of +15, +10, +5, and 0 dB. One practice list was administered at +10 dB SNR during each test session. Listeners were instructed to repeat back as much of each word as possible. A total of two lists (60 phonemes) were presented under each condition. The order of the 16 lists was randomly selected for each subject. Testing was completed under all signal-to-noise ratios for a given filtering condition before changing to a different filtering condition. Scores were based on the total percentage of phonemes repeated correctly. Data were arcsine transformed for statistical analyses (Studebaker, 1985).

RESULTS

Consonant Identification in Quiet

The mean percentage of consonants correctly identified under different filtering conditions is shown in Figure 2. Mean scores were similar for the two groups, and the highest mean scores were observed for the unfiltered condition. Scores dropped as the low-pass filter cutoff was reduced. A two-factor (filter setting, group) repeated-measures analysis of variance revealed a significant main effect of filtering [$F(3,42) = 12.50$, $p < .0001$]. There was no significant difference between scores for the two groups

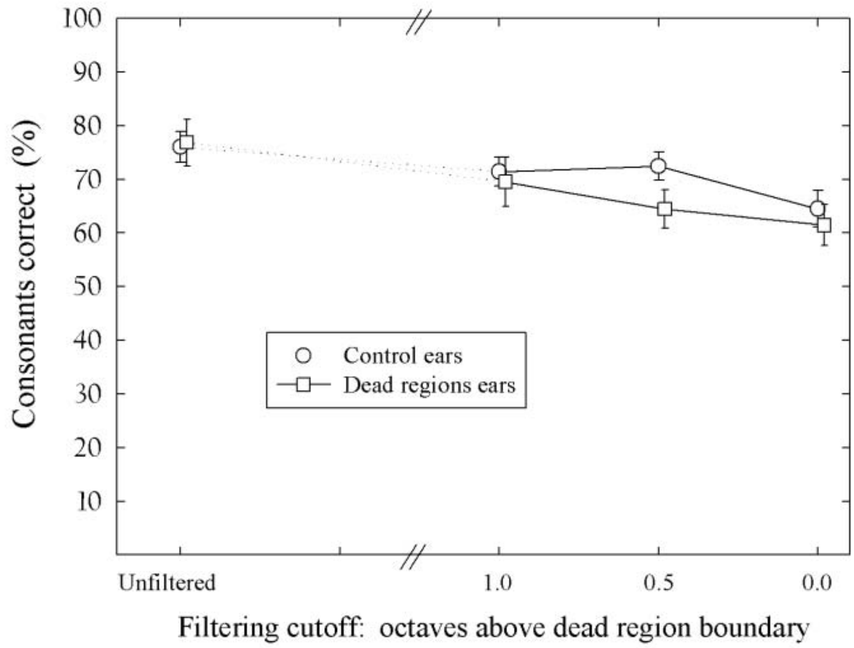

Figure 2. Mean consonant identification scores for VCV combinations in quiet for each filtering condition for control ears without dead regions and ears with suspected dead regions. Error bars show +/-1 standard error.

[F(1,14) = .15, p > .05] and no significant interaction between the two factors [F(3,42) = 1.41, p > .05].

Consonant Identification—Wide-Band Benefit

To assess the difference between the benefit from high-frequency amplification for the two groups, we calculated the "wide-band" benefit for each listener by subtracting the filtered score (obtained 1 octave above the estimated dead regions boundary) from the unfiltered score. A positive wide-band benefit means that scores were higher in the unfiltered condition than in the filtered condition. Mean wide-band benefit was 6.7 and 4.6 percentage points for the ears with and without suspected dead regions, respectively. This difference did not reach the 95% level of confidence [F(1,14) = 3.08, p > .05]. The magnitude of wide-band benefit was significantly greater than zero for both groups [dead regions: t(8) = 3.87, p < .01; no dead regions: t(8) = 2.80, p < .05]. These findings are consistent with the conclusion that in a quiet listening environment, listeners with suspected dead regions receive similar benefit from wide-band amplification as do listeners with similar hearing thresholds and no suspected dead regions.

Phoneme Recognition in Noise—CASPA Test

In the results reported below, mean scores for low noise levels were calculated from the average of phonemes scores for signal-to-noise ratios of +15 and +10 dB, and mean scores for high noise levels were calculated from the average scores for signal-to-noise ratios of +5 and 0.

Phoneme Recognition Scores

Mean phoneme recognition scores are shown in Figure 3 for the low and high noise levels. Overall, mean phoneme recognition scores were similar for the ears with and without suspected dead regions. In low levels of noise, scores for both groups increased as the filter cutoff increased, with maximum scores observed in the unfiltered condition. At high noise levels, phoneme recognition also increased as the filter cutoff increased, but the mean unfiltered score for the ears with dead regions did not increase between 1 octave and no filtering.

Wide-Band Benefit

The magnitude of benefit from wide-band high-frequency amplification, calculated by

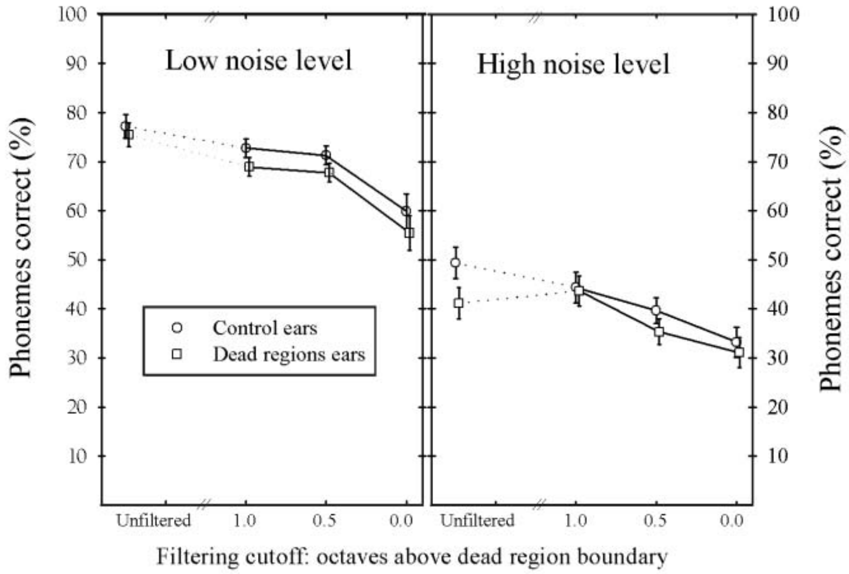

Figure 3. Mean phoneme recognition scores in low noise and high noise conditions for each filtering condition for control ears without dead regions and ears with suspected dead regions. Error bars show +/- 1 standard error.

subtracting the filtered score (1 octave above the boundary) from the unfiltered score, is shown in Figure 4. As before, a positive wide-band benefit means that scores were higher in the unfiltered condition than in the filtered condition. It can be seen that the pattern of wide-band benefit differs for the two groups as a function of noise level. The mean magnitude of the wide-band benefit was similar for the two groups under low noise conditions. In contrast, at high noise levels, the mean magnitude of the wide-band benefit

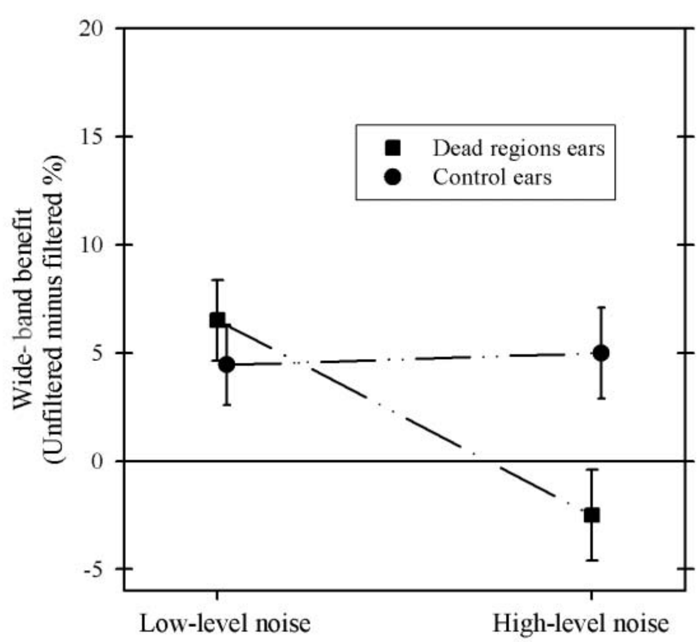

Figure 4. Mean wide-band benefit for phoneme recognition in low and high noise conditions (unfiltered score minus filtered score) for control ears without dead regions and ears with suspected dead regions. Error bars show +/-1 standard error.

for the ears with suspected dead regions was lower than the mean for the ears without dead regions.

A two-way repeated-measures analysis of variance (ear type, noise level) confirmed an interaction between ear type and noise [$F(1,14) = 7.73$, $p < .02$]. Newman-Keuls post hoc testing showed a significant difference between wide-band benefit for the ears with and without suspected dead regions at the high noise levels, but not at low noise levels. For the ears with suspected dead regions, the magnitude of wide-band benefit dropped significantly at the higher noise levels ($p < .05$), while remaining nearly unchanged for the ears without dead regions.

The results above are consistent with the conclusion that in relatively low levels of noise, listeners with suspected dead regions experience the same benefit from high-frequency amplification as listeners without dead regions. Under high noise conditions, however, listeners with dead regions may benefit less from maximizing high-frequency amplification than listeners without dead regions.

DISCUSSION

The findings of the present study support the conclusion that in quiet and in low levels of noise, listeners with and without suspected dead regions benefited equally from wide-band amplification. These findings differ from the findings of Vickers et al (2001), who found that performance obtained in quiet either reached an asymptote or deteriorated when stimuli were amplified more than ½ to 1 octave above the estimated boundary of the dead region.

One factor that may account for differences in results for the other two studies (Vickers et al, 2001; Baer et al, 2002) is the difference in the degree of hearing losses of the participants in the two studies. Participants in the present study had considerably less hearing loss (and higher dead regions boundaries) than subjects in the other studies. It is notable that in the Vickers study, three of the four participants who had audiometric thresholds and dead region boundaries closest to the participants in the present study (i.e., above 1500 Hz) showed slight, but continued, improvement in recognition scores when the maximum high-frequency amplification was provided, a finding that is consistent with the findings of the present study.

The pattern of benefit from wide-band amplification was somewhat different in the presence of high levels of background noise, however. At high noise levels, listeners with suspected dead regions experienced less benefit from wide-band amplification than listeners without dead regions. Performance reached an asymptote or deteriorated slightly when amplification was provided at frequencies higher than 1 octave above the estimated boundary of the dead regions. The individually determined signal-to-noise ratios used in the Baer study ranged from 0 to 6 dB, which were comparable to the 0–5 dB signal-to-noise ratios categorized as "high noise levels" in the present study. The pattern of results obtained by Baer et al (2002) for listeners with dead regions tested in background noise were similar to the results of the present study for the high levels of noise. Given that the TEN Test differentiates between listeners with and without dead regions on the basis of noise susceptibility, it is not surprising that listeners with and without dead regions have distinctly different patterns of amplification benefit in high levels of noise.

In the present study, participants identified as having suspected dead regions had abnormal TEN Test results in three or more contiguous frequencies. Clinicians who wish to use the TEN Test to identify dead regions for the purpose of modifying hearing aid frequency responses would be wise to disregard TEN Test results that indicate one or two isolated midfrequency dead regions. The reasons for this recommendation are two-fold. First, given the higher rate of false-positive TEN Test results in cases of isolated dead regions (Moore et al, 2000; Summers et al, 2003), the existence of dead regions in these cases is relatively uncertain. Second, even if one or two isolated dead regions do exist, it is unlikely that there will be negative consequences to providing amplification at these frequencies given that listeners generally benefit from amplification at least ½ to 1 octave above the boundary of the dead region.

Results of this and previous studies have several clinical implications. First, one should be cautious about concluding that a given patient cannot benefit from high-frequency information on the basis of high-frequency audiometric thresholds. In quiet and low noise listening situations, high-frequency amplification should not necessarily be limited for patients with dead regions when estimated boundaries of the dead regions fall at or above 2000 Hz (or when 4000 Hz thresholds are 80 dB or less). In fact, these patients appear to benefit as much as patients without dead regions. Based on the work of Vickers et al (2001) and Baer et al (2002), however, one should exert caution in amplifying frequencies more than one octave above the estimated boundary of a dead region when the boundary is less than 2000 Hz (and thresholds are greater than 80 dB HL). In high noise situations, patients with dead regions may not benefit from extending high-frequency amplification more than 1 octave above the estimated boundary of the dead regions, regardless of the estimated dead regions boundary.

It is important for clinicans to bear in mind that the conclusions of the present study are based on mean data. While these conclusions may serve as general guidelines, audiologists should recognize that individual differences do exist, and the observations described here will not apply to all patients. In addition, it is important to note that the subject population of the present study was limited to adults with acquired hearing loss, most of whom had a history of noise exposure. It is not clear to what extent the findings can be generalized to children or to adults with other etiologies.

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REFERENCES

Baer T, Moore BCJ, Kluk K. (2002) Effects of low-pass filtering on the intelligibility of speech in noise for people with and without dead regions at high frequencies. *J Acoust Soc Am* 112:1133–1144.

Ching TY, Dillon H, Byrne D. (1998) Speech recognition of hearing-impaired listeners predictions from audibility and the limited role of high-frequency amplification. *J Acoust Soc Am* 103:1128–1140.

Cornelisse LE, Seewald RC, Jamieson DG. (1995) The input/output formula: a theoretical approach to the fitting of personal amplification devices. *J Acoust Soc Am* 97:1854–1864.

DADISP. (1996) DSP Development Corporation, Cambridge, MA.

Hogan C, Turner C. (1998) High frequency audibility: benefits for hearing-impaired listeners. *J Acoust Soc Am* 104:432–441.

Mackersie CL, Boothroyd A, Minniear D. (2001) Evaluation of a computer-assisted speech perception assessment test (CASPA). *J Am Acad Audiol* 13:38–49.

Moore BCJ. (2001) Dead regions in the cochlea: diagnosis, perceptual consequences and implications for the fitting of hearing aids. *Trends Amplification* 5:1–31.

Moore BCJ, Glasberg BR. (1998) Use of a loudness model for hearing-aid fitting. I. Linear hearing aids. *Br J Audiol* 32:317–335.

Moore BCJ, Huss M, Vickers DA, Glasberg BR, Alcantara JI. (2000) A test for the diagnosis of dead regions in the cochlea. *Br J Audiol* 34:205–224.

Studebaker GA. (1985) A "Rationalized" arcsine transform. *J Speech Hear Res* 28:455–462

Summers V, Molis MR, Museh H, Walden BE, Surr RK, Cord MT. (2003) Identifying dead regions in the cochlea: psychophysical tuning curves and tone detection in threshold-equalizing noise. *Ear Hear* 24:133–142.

Vickers DA, Moore BCJ, Baer T. (2001) Effects of low-pass filtering on the intelligibility of speech in quiet for people with and without dead regions at high frequencies. *J Acoust Soc Am* 110:1164–1175.