Do tests for cochlear dead regions provide important information for fitting hearing aids?[a] (L)

Van Summers[b]
Army Audiology and Speech Center, Walter Reed Army Medical Center, Washington, DC 20307-5001

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For listeners with cochlear hearing loss, cochlear damage may include ''dead regions'' with no functioning inner hair cells and/or associated neurons. Recent studies indicate that amplifying frequencies more than 1.7 times the edge frequency ($1.7F_e$) of a high-frequency dead region is unlikely to improve (and may reduce) speech scores [Vickers *et al.*, J. Acoust. Soc. Am. **110**, 1164–1175 (2001); Baer *et al.*, J. Acoust. Soc. Am. **112**, 1133–1144 (2002)]. These results were taken as evidence that tests to identify dead regions could improve hearing aid fitting. In the current study, practicing audiologists examined audiograms of listeners diagnosed as having high-frequency dead regions. The audiologists were given no specific information regarding dead regions for any individual, and were asked to base amplification decisions entirely on the audiograms. Most audiologists did not recommend amplification of frequencies with hearing losses exceeding 90 dB HL. Reexamination of speech results reported by Vickers *et al.* and Baer *et al.* indicated that limiting amplification based on audiograms alone (90-dB rule) or on specific testing for dead regions ($1.7F_e$ rule) produced similar performance. Thus, testing for dead regions may not provide important information for hearing aid fitting that is not already available in the audiogram. [DOI: 10.1121/1.1649931]

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I. INTRODUCTION

For listeners with moderate-to-severe high-frequency hearing loss, the basal cochlea may contain ''dead regions'' where inner hair cells and/or associated neurons are entirely nonfunctional. The auditory nerve will not receive input from these regions. However, at high presentation levels, frequencies normally processed in these regions may still be detected as a result of spread of excitation to adjacent portions of the cochlea.

Vickers, Moore, and Baer (2001) and Baer, Moore, and Kluk (2002) examined whether listeners with high-frequency dead regions received benefit from amplified high-frequency speech. Psychophysical tuning curves (PTCs) and tone-detection thresholds in ''threshold-equalizing noise'' (TEN) were used to identify hearing-impaired listeners with and without high-frequency dead regions. Speech recognition performance was then tested in quiet (Vickers *et al.*, 2001) and in noise (Baer *et al.*, 2002) using amplified broadband speech and amplified low-pass speech with high-frequency regions removed [amplification based on the ''Cambridge'' fitting rule (Moore and Glasberg, 1998)]. The results of both studies indicated that the presence or absence of high-frequency dead regions was directly linked to whether subjects benefited from high-frequency speech cues. Subjects without high-frequency dead regions performed best in broadband speech. Subjects with dead regions did as well, and sometimes better, in low-pass speech than in broadband conditions. Both Vickers *et al.* (2001) and Baer *et al.* (2002) interpreted their results as suggesting that tests to diagnose the presence and frequency extent of dead regions may provide a useful clinical tool in making amplification decisions, and that amplification of frequencies falling well within high-frequency dead regions may not be advisable. Specifically, amplification of frequencies more than 1.7 times the edge frequency of a high-frequency dead region ($1.7F_e$) may not provide any benefit (Vickers *et al.*, 2001; Baer *et al.*, 2002).

A complication in interpreting these results is that in both Vickers *et al.* (2001) and Baer *et al.* (2002), listeners diagnosed as having high-frequency dead regions had significantly more high-frequency hearing loss than listeners without dead regions. Audiograms for the ten ears with no dead regions and nine ears with dead regions from the two studies are plotted in Fig. 1 (solid lines and dashed lines, respectively; the heavy solid line and the filled symbols in the figure will be described later). Clearly, the audiograms for these two sets of ears diverge above 2000 Hz, with ears diagnosed as having high-frequency dead regions showing greater high-frequency losses. This leads to the question of whether a separate test for dead regions is likely to be clinically valuable or if the relevant information provided by this testing is already available in the audiograms. Rankovic (2002) recently reported articulation index (AI) analyses of the speech results reported by Vickers *et al.* (2001) and concluded that ability to benefit from high-frequency amplification can be accurately predicted based on the audiogram and presentation levels alone [but see Moore (2002) for an alternative interpretation of Rankovic's findings].

Based on Rankovic (2002) and Moore (2002), it is unclear whether tests for high-frequency dead regions will lead to better clinical decisions about high-frequency amplification than can be made based on audiograms alone. To exam-

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[b]Electronic mail: walter.summers@na.amedd.army.mil

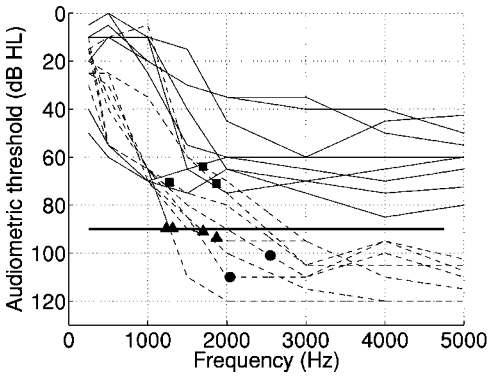

FIG. 1. Audiograms for nine ears with high-frequency dead regions (dashed lines) and ten ears with no dead regions (solid lines) as previously reported in Vickers *et al.* (2001) and Baer *et al.* (2002). Intersections of audiograms with the heavy line at 90 dB HL indicate cutoff frequencies for amplification based on the 90-dB rule. Symbols indicate cutoffs based on 1.7 times the estimated low-frequency edge of the dead region.

ine this question, practicing audiologists were shown audiograms for ears diagnosed as having high-frequency dead regions. Based solely on the audiograms, the audiologists were asked to assess whether they would prescribe broadband amplification, and, if not, to estimate the frequency limit of where amplification was likely to provide benefit. As reported below, experienced audiologists were unlikely to expect benefit from amplification once thresholds exceeded about 90 dB HL. The speech results reported by Vickers *et al.* (2001) and Baer *et al.* (2002) were then reexamined to see whether limiting high-frequency amplification based on testing for dead regions led to better speech performance than limiting based on the audiogram and a 90 dB HL "rule of thumb."

II. METHODS

Eleven audiologists working in the Army Audiology and Speech Center at Walter Reed Army Medical Center participated by completing a one-page handout. The handout contained a single graph with six lines representing audiograms for the six ears identified as having high-frequency dead regions in Baer *et al.* (2002, Table I). These are six of the nine ears with dead regions shown in Fig. 1. The following instructions appeared on the handout: "The graph below shows thresholds for six hearing-impaired listeners. If these were the only data you had for each listener, would you be likely to attempt broadband amplification aimed at providing signal audibility all the way up to 5 kHz in every case? If not, at what frequency would you be likely to "give up"? Please place an X on each of the six threshold lines at the frequency where you feel the loss has become severe enough so that amplification is probably unlikely to provide benefit. In cases where you would provide broadband amplification, put your X at 5 kHz."

III. RESULTS

Figure 2 shows the six audiograms included in the handout and the responses provided by one of the audiologists (the X's). Note that these data show little variability on the *y* axis, and that this audiologist would be unlikely to provide

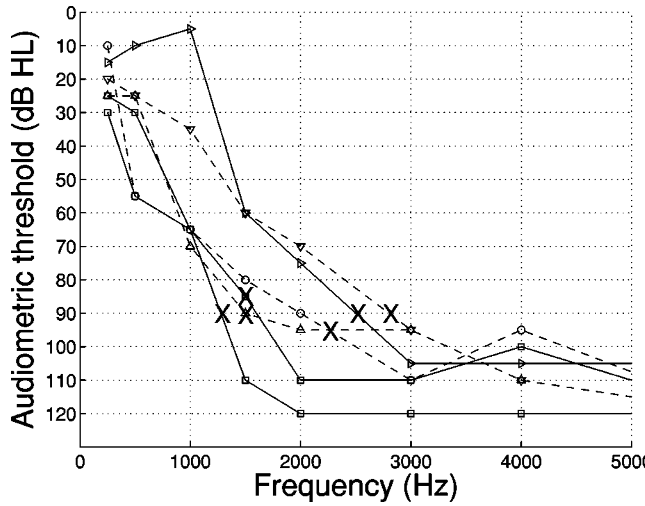

FIG. 2. The six audiograms as presented in the handout and responses provided by one audiologist (X's). Note that the handout used a linear frequency scale rather than the log scale more commonly seen in audiograms. This allowed for finer frequency distinctions to be indicated in the region above 1000 Hz.

high-frequency amplification once the hearing loss exceeded about 90 dB HL. For each audiologist, threshold values for the six X's on the completed handout (in dB HL) were averaged to get a mean amount of hearing loss where high-frequency amplification was likely to be discontinued. These mean values (and their standard deviations) are plotted in Fig. 3 as a function of years of experience as a practicing audiologist.

The data in Fig. 3 show some variability that appears to be related to years of clinical experience. Means displayed in the right-hand part of the figure, representing audiologists with more than 10 years of experience, indicate that amplifying high frequencies would not be attempted when losses exceeded about 90 dB HL. The left-hand portion of the figure shows that most of the audiologists with fewer years of experience would provide amplification for greater amounts of loss. The data from audiologists with over 10 years of

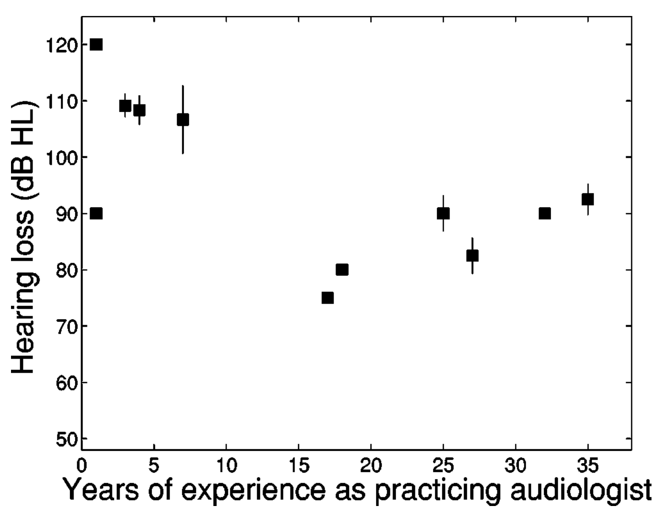

FIG. 3. Mean pure-tone hearing loss at the recommended cutoff frequency for amplification based on responses to the handout. Means are plotted as a function of years of experience as a practicing audiologist. Error bars indicate ± one standard deviation.

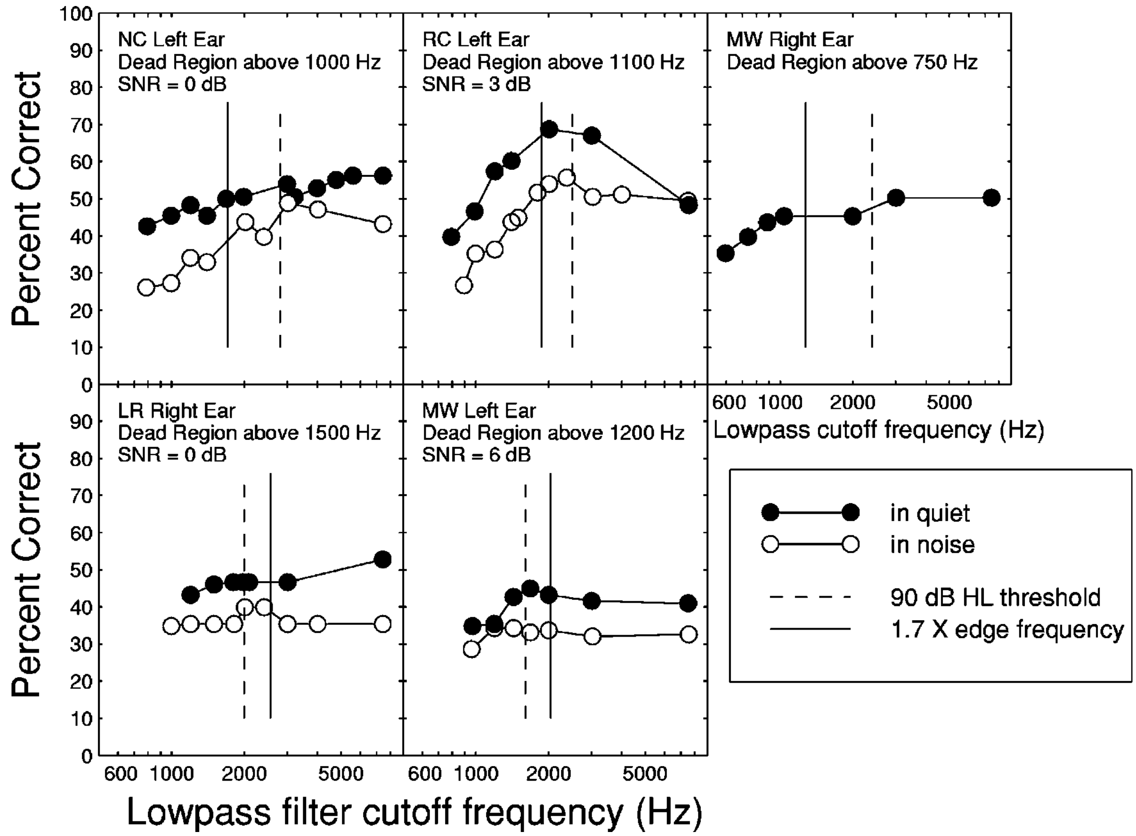

FIG. 4. Identification performance for amplified speech as a function of low-pass filter cutoff frequency [data originally reported in Vickers *et al.* (2001) and Baer *et al.* (2002)]. Vertical lines indicate recommended cutoff frequencies for amplification based on 90-dB and $1.7F_e$ rules (dashed and solid lines, respectively). Signal-to-noise ratios used during in-noise testing are indicated in figure panels.

experience suggest a simple rule. That is, limit high-frequency amplification to frequencies with losses no greater than 90 dB HL. This "90-dB rule" provides a recommended frequency cutoff for high-frequency amplification that can be compared to the cutoff indicated by the testing for dead regions ($1.7F_e$ rule). (It should be noted that most of the audiologists did not simply follow the 90-dB rule in responding to the survey—there were in fact only two instances where surveys were returned with all six responses at 90 dB HL. The 90-dB rule was selected for comparison to the $1.7F_e$ rule because the audiologists with more than 10 years of experience generally did not recommend amplification when thresholds exceeded 90 dB HL and because the rule provides a recommended frequency cutoff for high-frequency amplification directly from the audiogram.)

Figure 1 can now be reconsidered in terms of the recommended cutoff frequencies for high-frequency amplification based on the two rules (90-dB and $1.7F_e$). Using the 90-dB rule, amplification would only be provided for frequencies where thresholds fall above the heavy solid line in the figure (90 dB HL). Note first that all thresholds fall above this line for the ears with no dead regions. Thus, based on the 90-dB rule, broadband amplification would be indicated for these ears. This fits with the results reported by Vickers *et al.* (2001) and Baer *et al.* (2002): these subjects performed best with broadband amplification. For these ten ears, the 90-dB rule led to the same recommendation in terms of amplification as the additional testing required to specifically identify dead regions. Thus, for these ears, it appears that testing for dead regions would not have affected clinical decisions regarding amplification.

For the nine ears with high-frequency dead regions, recommended cutoff frequencies for high-frequency amplification based on the 90-dB rule can be compared to recommended cutoffs based on testing to locate the edge frequencies of dead regions. For these ears, the filled symbols in Fig. 1 indicate cutoff frequencies based on the $1.7F_e$ rule [using edge frequency values reported by Vickers *et al.* (2001) and Baer *et al.* (2002)]. For four of these ears, the recommended cutoff frequency based on $1.7F_e$ was nearly equal to 90 dB HL (triangles in Fig. 1). Thus, for these ears, the recommended cutoff frequency for high-frequency amplification would be essentially equivalent using either the 90-dB or the $1.7F_e$ rules. These ears represent additional instances where testing to assess dead regions would not have altered decisions about amplification.

Cutoff frequencies based on $1.7F_e$ were lower than cutoffs based on the 90 dB HL threshold for three ears in Fig. 1 (squares in the figure). That is, for these three ears, the 90-dB rule recommends extending amplification to slightly higher frequencies than $1.7F_e$. For two ears the $1.7F_e$ rule recommends amplifying frequency regions with more than 100 dB of hearing loss (circles in Fig. 1). In these instances, the 90-dB rule limits high-frequency amplification slightly more than the $1.7F_e$ rule.

The five ears considered in the previous paragraph are cases in which the 90-dB and $1.7F_e$ rules led to slightly different recommendations in terms of high-frequency amplification. In these instances, speech recognition data can be examined to determine if either rule led to better overall performance. The speech results reported by Vickers *et al.* (2001) and Baer *et al.* (2002) for these ears allow this comparison and are replotted in Fig. 4. Each panel of the figure shows speech recognition performance by a single ear for amplified speech under various lowpass conditions. Within each panel, performance is plotted as a function of the lowpass cutoff frequency of amplified speech. Movement to the right within each panel shows how performance changed as more and more high-frequency portions of the signal were presented. The rightmost point in each panel represents amplified broadband speech. As noted by both Vickers *et al.* (2001) and Baer *et al.* (2002), for these and other listeners with high-frequency dead regions, there appears to be a point at which performance stops improving with the addition of more high-frequency cues. For some ears, (e.g., RC–left ear), lowpass filtering appears to result in better performance than broadband amplification. The question is whether the 90-dB rule provides as accurate an estimate of the appropriate cutoff frequency for amplification in these ears as the cutoff frequency indicated by specific testing for dead regions. The vertical lines in Fig. 4 indicate recommended cutoff frequencies for amplification based on the 90 dB and $1.7F_e$ rules and allow an examination of this question.

The upper panels in Fig. 4 represent ears where cutoff frequencies were slightly higher based on the 90-dB rule than the $1.7F_e$ rule (ears represented by squares in Fig. 1). For these ears, speech scores showed a small improvement when amplification was extended above $1.7F_e$ up to the 90-dB threshold. For the data in these three panels, speech scores (measured or estimated based on interpolation where necessary) were, on average, about 3% higher in the more broadband amplification provided by the 90-dB rule than the more narrow-band amplification prescribed by the $1.7F_e$ rule. This small improvement in performance was statistically significant $[t(4)=2.848, p<0.05]$.

The lower panels in Fig. 4 represent the two cases where amplification would extend to higher frequencies based on the $1.7F_e$ rule than based on the 90-dB rule (circles in Fig. 1). For these two ears, the $1.7F_e$ rule leads to amplification of frequency regions with more than 100 dB of hearing loss. The amplification of frequencies with this much hearing loss did not lead to improved performance over amplification restricted to frequencies with hearing loss no greater than 90 dB HL.

It was noted already that the 90-dB rule provides only an approximation to the actual frequency cutoff values recommended by the audiologists with more than 10 years experience who were surveyed. In general, the individual cutoff frequencies recommended by these clinicians produced similar percent correct scores in the speech tasks as the 90-dB and $1.7F_e$ rules. For these (and perhaps many other) experienced audiologists, specific testing for dead regions may not improve hearing aid fitting decisions that would be made without this testing.

IV. CONCLUSIONS

Testing for the presence of cochlear dead regions may be of clinical value if the results lead to improved decisions about amplification for hearing-impaired listeners. However, if the important clinical information provided by this testing is available directly from the audiogram, the additional testing is clearly unnecessary. In the current study, a simple rule based directly on the audiogram led to limiting high-frequency amplification for the same listeners and for similar frequency regions as indicated by specific testing for dead regions. The results suggest that tests to identify high-frequency dead regions do not improve clinical decisions relating to high-frequency amplification compared to a simple rule based on absolute thresholds.

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