Recognition of nonsense syllables by hearing-impaired listeners and by noise-masked normal hearers

Larry E. Humes
Division of Hearing and Speech Sciences, Vanderbilt University School of Medicine, Nashville, Tennessee 37232

Donald D. Dirks, Theodore S. Bell, and Gail E. Kincaid
Division of Head and Neck Surgery, U.C.L.A. School of Medicine, Los Angeles, California 90024

(Received 4 February 1986; accepted for publication 15 October 1986)

In the present study, speech-recognition performance was measured in four hearing-impaired subjects and twelve normal hearers. The normal hearers were divided into four groups of three subjects each. Speech-recognition testing for the normal hearers was accomplished in a background of spectrally shaped noise in which the noise was shaped to produce masked thresholds identical to the quiet thresholds of one of the hearing-impaired subjects. The question addressed in this study is whether normal hearers with a hearing loss simulated through a shaped masking noise demonstrate speech-recognition difficulties similar to those of listeners with actual hearing impairment. Regarding overall percent-correct scores, the results indicated that two of the four hearing-impaired subjects performed better than their corresponding subgroup of noise-masked normal hearers, whereas the other two impaired listeners performed like the noise-masked normal listeners. A gross analysis of the types of errors made suggested that subjects with actual and simulated losses frequently made different types of errors.

PACS numbers: 43.71.Ky, 43.71.ES, 43.66.Dc

INTRODUCTION

The psychoacoustic and speech-recognition performance of listeners with sensorineural hearing loss has been studied by several investigators in recent years (for recent reviews, see Jesteadt, 1978; Scharf and Florentine, 1982; Humes, 1982; and Moore, 1983). It has been frequently suggested that the speech-recognition difficulties experienced by listeners having sensorineural hearing loss are the result of psychoacoustic abnormalities accompanying the cochlear pathology and not simply the threshold elevation (Bonding, 1979; Tyler et al., 1980; Patterson et al., 1982). Appearing to support this conclusion is the frequent observation that normal hearers listening to filtered speech perform better than hearing-impaired subjects having comparable hearing loss. Such an outcome has been observed in several studies (Wang et al., 1978; Walden et al., 1981; Kiukaanniemi, 1979, 1980). It is reasoned that if the filtering effects of threshold elevation were responsible for the speech-recognition performance of hearing-impaired listeners, then the normals should also perform poorly when listening to appropriately filtered speech. Although the performance of normal hearers is reduced by filtering the signal, the normal hearers listening to filtered speech typically outperform the impaired subjects. It is frequently suggested that some additional abnormality beyond the threshold elevation may be operating in the impaired ears to account for this difference in performance between groups.

Filtered signals presented to normal hearers, however, provide a better simulation of hearing loss associated with conductive pathology than with sensorineural impairment. Both filtering and conductive pathology appear to simply attenuate incoming signal energy prior to stimulation of the cochlea. It has been suggested previously (Milner, 1982; DeGennaro et al., 1981; Humes, 1982) that the most appropriate control condition for comparison to sensorineural hearing impairment is the introduction of broadband masking noise shaped to produce masked thresholds in the normal hearers that are identical to those of the impaired ears. The masking process responsible for threshold elevation is believed to be predominantly of cochlear origin (Fletcher, 1953; Zwicker and Feldtkeller, 1967; Zwicker, 1975, 1982). In addition, noise-masked normal listeners demonstrate loudness recruitment comparable to that observed in ears with sensorineural pathology (Lochner and Burger, 1961; Stevens, 1966).

The present study sought to evaluate how accurately noise-masked normal listeners simulate sensorineural listeners in their speech-recognition performance. If some phenomenon other than threshold elevation of cochlear origin and accompanying loudness recruitment is at least partially responsible for the speech-recognition difficulties of listeners with sensorineural impairment, then one would expect the sensorineural listeners to perform more poorly than the normal hearers listening in noise. If, however, similar performance is observed for both groups or the impaired subjects perform better than the noise-masked normal listeners, then no additional abnormality, beyond threshold elevation of cochlear origin and accompanying loudness recruitment, need be invoked to explain the speech-recognition performance of the impaired listeners. Superior performance by the hearing-impaired listeners over that of noise-masked listeners is reduced by filtering the signal, the normal hearers listening to filtered speech typically outperform the impaired subjects. It is frequently suggested that some additional abnormality beyond the threshold elevation may be operating in the impaired ears to account for this difference in performance between groups.

Filtered signals presented to normal hearers, however, provide a better simulation of hearing loss associated with conductive pathology than with sensorineural impairment. Both filtering and conductive pathology appear to simply attenuate incoming signal energy prior to stimulation of the cochlea. It has been suggested previously (Milner, 1982; DeGennaro et al., 1981; Humes, 1982) that the most appropriate control condition for comparison to sensorineural hearing impairment is the introduction of broadband masking noise shaped to produce masked thresholds in the normal hearers that are identical to those of the impaired ears. The masking process responsible for threshold elevation is believed to be predominantly of cochlear origin (Fletcher, 1953; Zwicker and Feldtkeller, 1967; Zwicker, 1975, 1982). In addition, noise-masked normal listeners demonstrate loudness recruitment comparable to that observed in ears with sensorineural pathology (Lochner and Burger, 1961; Stevens, 1966).

The present study sought to evaluate how accurately noise-masked normal listeners simulate sensorineural listeners in their speech-recognition performance. If some phenomenon other than threshold elevation of cochlear origin and accompanying loudness recruitment is at least partially responsible for the speech-recognition difficulties of listeners with sensorineural impairment, then one would expect the sensorineural listeners to perform more poorly than the normal hearers listening in noise. If, however, similar performance is observed for both groups or the impaired subjects perform better than the noise-masked normal listeners, then no additional abnormality, beyond threshold elevation of cochlear origin and accompanying loudness recruitment, need be invoked to explain the speech-recognition performance of the impaired listeners. Superior performance by the hearing-impaired listeners over that of noise-masked

*Present address: Department of Speech and Hearing Sciences, Indiana University, Bloomington, IN 47405.
normals closely matched for signal audibility, however, while not suggestive of additional processing difficulties in the impaired listeners, could compromise the utility of noise-masked normal hearers as a model of sensorineural hearing loss.

It should be noted that this approach has been pursued by others in recent years, although only a limited number of subjects or a limited range of speech stimuli have typically been employed (Milner, 1982; Braida et al., 1985; Zurek and Delhorne, 1986; Fabry and Van Tasell, 1986). All possible outcomes, moreover, have been observed in these earlier studies. Some noise-masked normal hearers performed better than impaired listeners, some performed the same, while still others performed more poorly.

I. METHODS

A. Subjects

A total of 16 subjects participated in the present study. Four subjects had bilaterally symmetrical sensorineural hearing loss of presumed cochlear origin. All four had moderate-to-severe high-frequency hearing loss with varying degrees of impairment in the low and mid frequencies. Three of the four subjects had their hearing loss since birth or early childhood while one (HI-02) had sudden onset of hearing loss approximately 4 years prior to the present testing. Subject ages were 32, 56, 17, and 36 years for subjects HI-01, HI-02, HI-03, and HI-04, respectively. All impaired subjects had normal tympanograms.

Three normal hearers were selected for each of the hearing-impaired subjects to serve as noise-masked normal listeners. By using three noise-masked normal hearers for each impaired subject, interindividual variability in the performance of normal listeners with identical masked audiograms could be taken into consideration when comparing the performance of the hearing-impaired to the noise-masked normal-hearing subjects. Differences between impaired and masked-normal listeners could then be evaluated in light of the observed between-subject variability of the noise-masked normal hearers. All 12 subjects in this group had pure-tone thresholds from 125-8000 Hz < 15 dB HL (ANSI, 1969). Tympanograms were normal and acoustic reflexes were present at 100 dB HL at 1000 Hz. Normal hearers ranged in age from 19-32 years.

B. Apparatus and stimulus generation

For measurement of pure-tone threshold, stimuli were generated digitally by a PDP-11/23 laboratory minicomputer so as to have a 350-ms duration (from onset to offset) with a 25-ms raised-cosine rise–fall time. The stimuli were output through a 12-bit digital-to-analog converter at a rate of 25 kHz and low-pass filtered at 10 kHz. The stimuli were then routed through a programmable attenuator that was controlled by the computer and sent to one channel of a speech audiometer (Grason-Stadler model 162, GS-162) prior to transduction by a TDH-49 earphone mounted in an MX-41/AR cushion. A second GS-162 speech audiometer was used to produce a speech-shaped noise at an overall sound pressure level of 65 dB. This noise was routed to the nontest ear of all subjects to assure that listening was restricted to the test ear.

For the noise-masked normal hearers it was necessary to mix the test signal with a shaped masking noise. The latter was produced by a random-noise generator (GenRad 1390-B) which, following attenuation (Hewlett-Packard 3500D), was shaped by a 1/3 octave-band multifold filter (GenRad 1925). The output of the multifold was then routed to the second channel of the GS-162 speech audiometer used for the test signal. The output of this channel was set to maximum attenuation when testing the hearing-impaired subjects.

For speech-recognition testing, the C.U.N.Y. Nonsense Syllable Test (NST; Resnick et al., 1975) was employed. This test is comprised of vowel–consonant and consonant–vowel nonsense syllables spoken by a male talker and arranged in 11 subtests. Within each subtest, consonant position (syllable initial or syllable final), consonant voicing (voiced or voiceless), and vowel environment (/a,u,i/) are constant while consonant place and/or manner of articulation vary. Nine of the original subtests were used in this investigation (subtests 1, 2, 3, 6, 7, 8, 9, 10, and 11). These stimuli had been previously digitized (Kamm et al., 1985). The NST stimuli were routed through equipment identical to that of the pure-tone signals following output through the digital-to-analog converter. A 400-Hz calibration tone digitized from the master tape of the NST materials was used for calibration and specification of presentation levels. All stimulus levels for pure tones, speech signals, and noise stimuli are referenced to the sound pressure level generated in an NBS-9A 6-cm³ coupler.

C. Procedures

Pure-tone thresholds for all subjects were obtained using a two-alternative forced-choice paradigm designed to estimate the 79.6 percent-correct point on the psychometric function relating percent-correct signal detection to stimulus level (Levitt, 1971). Three successive correct responses were followed by a decrease in signal level while incorrect responses were followed by an increase in the level of the signal. A total of 15 reversals in signal level were employed for a single threshold estimate. Signal increments or decrements were 10 dB for the first five reversals and 2 dB for the last ten. Of the last ten reversals, the first two were discarded with the midpoint of the last eight representing threshold.

Pure-tone thresholds were measured for frequencies at 1/3-octave intervals from 125–8000 Hz. The 19 test frequencies were divided into two subgroups by selecting every other test frequency from 125–8000 Hz. Test order within a subgroup was randomized. After thresholds were obtained for both subgroups the procedure was repeated a second time. Thresholds reported are the means of these two estimates.

Identical psychophysical procedures were employed with the hearing-impaired and normal-hearing subjects. Once the quiet thresholds for the hearing-impaired subjects had been established, the pure-tone testing for the normal hearers proceeded. Initial multifold settings required to shape the noise so as to produce masked thresholds identical to the quiet thresholds of the corresponding hearing-im-
paired subject were established from calculations. The calculations made use of the critical ratio and the 1/3-octave-band noise levels measured for a flat multifilter setting. With the exception of one group of subjects, those simulating HI-03, these initial settings required only minor adjustments to achieve the desired goal that masked threshold be within 3 dB of the impaired subject's quiet threshold for at least 17 of the 19 test frequencies. In most instances this goal was achieved. If, however, the desired goal was not achieved at the end of three 2-h sessions, then the last set of multifilter adjustments were considered final.

Speech-recognition testing proceeded identically for the hearing-impaired and noise-masked normal-hearing subjects. The test items for a given randomly selected subtest were administered six times in completely random fashion before proceeding to another subtest. All subtests were presented initially at 86 dB SPL for practice. Testing was then performed at 66, 76, and 86 dB for three subject groups (HI-01, HI-02, HI-04, and those noise-masked normals simulating these configurations) and 56, 66, and 76 dB for the remaining subject group (HI-03 and associated noise-masked normals). Presentation levels were selected to encompass the linear portion of the performance-intensity function while attempting to maintain uniformity across subjects. Order of testing for the three test levels was randomized for each subject.

The speech-recognition testing concluded with a retest of several subtests administered at one of the lower two presentation levels. Generally, those subtests for which the subjects recognized between 20% and 50% of the items correctly were retested. This typically amounted to four or five subtests per subgroup. This expanded set of data was to be used for subsequent analysis of confusion patterns, an analysis that is not reported here. These data, however, are used in the present study to evaluate the test-retest reliability of the individual subtest scores.

Subjects were seated in a sound-treated room for testing. A response box, under computer control, was used to activate appropriate lights and buttons for both the pure-tone and speech-recognition testing. The 2AFC pure-tone threshold paradigm utilized a 500-ms warning light followed by a 500-ms delay. Each interval was then marked by a light activated for 350 ms with a 500-ms delay between intervals. A response light followed the second interval and indicated that the computer was ready to receive the subject's response. The subject's response terminated the trial.

The same warning light parameters were used for speech-recognition testing. For this testing, however, no interval light was required. In addition, once the response light was activated, the subject was required to press the button corresponding to the syllable heard. A removable label, containing orthographic representations of the nonsense syllables in a particular subtest, was positioned above an array of buttons. Each button corresponded to one of the possible items on that subtest.

Trial-to-trial feedback regarding correct responses was provided only for the pure-tone testing. The hearing-impaired subjects required 6–8 h of testing to complete the study. The noise-masked normal-hearing listeners participated for 8–12 h. All subjects were paid for their participation.

II. RESULTS

A. Pure-tone thresholds

Figure 1 displays the mean pure-tone thresholds obtained from the four hearing-impaired subjects of this study. For comparison, a set of reference data from normal-hearing subjects is also provided (filled circles). The latter values represent mean thresholds from 12 normal-hearing subjects tested previously in the same laboratory with identical psychophysical procedures. As indicated in this figure, all impaired subjects in the present study had moderate-to-severe high-frequency hearing loss with varying amounts of hearing loss in the low and mid frequencies.

Table I provides the root-mean-square (rms) error between the quiet thresholds of the impaired listener and each of the three corresponding noise-masked normal listeners. Figure 2 illustrates the agreement between the thresholds of the poorest match of the three noise-masked normals and the thresholds from the corresponding hearing-impaired subject for each of the four impaired subjects. These data, together with the rms-error values appearing in Table I, indicate that a close match was achieved between the impaired subjects and the noise-masked normal hearers. The poorest match overall was observed in the subgroup simulating impaired subject HI-03 (lower left panel of Fig. 2). This impaired subject had the steepest slope in audiometric configuration. The difference between maximum and minimum hearing loss for this subject exceeded the working range of the multifilter. Unable to match both the maximum and minimum thresholds, it was decided to match the maximum thresholds as closely as possible at the expense of the minimum thresholds. The poor match is apparent in the region between 400 and 1000 Hz for the data from subject MN-03B shown in the lower left panel of Fig. 2. The masked thresholds for the other two noise-masked normal listeners of this subgroup also varied from those of the impaired subject in this frequency region.

FIG. 1. Mean pure-tone thresholds for the four hearing-impaired subjects in this study. For comparison, the filled circles show mean pure-tone thresholds for normal hearers (N = 12) tested with identical procedures.
TABLE I. The rms error between masked thresholds of a normal-hearing subject and quiet thresholds of the corresponding hearing-impaired subject.

<table>
<thead>
<tr>
<th>Subject</th>
<th>rms error (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MN-01A</td>
<td>4.5</td>
</tr>
<tr>
<td>MN-01B</td>
<td>4.2</td>
</tr>
<tr>
<td>MN-01C</td>
<td>4.0</td>
</tr>
<tr>
<td>MN-02A</td>
<td>3.5</td>
</tr>
<tr>
<td>MN-02B</td>
<td>3.8</td>
</tr>
<tr>
<td>MN-02C</td>
<td>2.2</td>
</tr>
<tr>
<td>MN-03A</td>
<td>4.9</td>
</tr>
<tr>
<td>MN-03B</td>
<td>6.1</td>
</tr>
<tr>
<td>MN-03C</td>
<td>5.1</td>
</tr>
<tr>
<td>MN-04A</td>
<td>3.2</td>
</tr>
<tr>
<td>MN-04B</td>
<td>3.1</td>
</tr>
<tr>
<td>MN-04C</td>
<td>2.9</td>
</tr>
</tbody>
</table>

B. Speech-recognition performance

Figure 3 illustrates the performance-intensity functions for each of the four hearing-impaired subjects. Each data point represents the mean overall percent correct for 438 syllable presentations (73 syllables presented six times). The presentation levels employed appear to have adequately defined the linear portion of the performance-intensity function. Floor and ceiling effects are not apparent and the levels have defined a wide range of performance for each subject (at least a 35% difference between the minimum and maximum performance).

Regarding overall speech-recognition performance, comparison between the data from the hearing-impaired subject and the corresponding noise-masked normals for each of the four subgroups suggested the following outcomes: (1) Hearing-impaired subjects performed better than noise-masked normal hearers; or (2) hearing-impaired subjects performed the same as noise-masked normals. An example of the first outcome is depicted in Fig. 4. This figure provides performance-intensity functions for each subtest and for the overall (NST) score. The data for HI-01 are represented by the filled circles connected by solid lines while the other symbols represent data from each of the three corresponding noise-masked normal subjects. As the data in the lower right panel labeled "ALL" indicate, the overall NST score of this impaired subject was better than that of every noise-masked normal hearer at all presentation levels. For the data in each panel of Fig. 4, as well as Figs. 5, 6, and 7, the following criterion was used to define equality of per-
performance between the hearing-impaired listener and the corresponding noise-masked normal hearers. If the scores of the hearing-impaired subject on a particular subtest were within the range of scores observed for the three noise-masked normal hearers on that same subtest at two or more presentation levels, then performance of the impaired subject was considered to be the same as that of the noise-masked normal hearers. Otherwise, performance of the impaired listener was considered to be either better or worse than that of the normal hearers listening in noise. On a few occasions, the performance of the impaired subject relative to that of the group of noise-masked normal hearers varied with presentation level such that one level yielded equal performance, one level yielded superior performance by the hearing-impaired subject, and the remaining level revealed superior performance by the noise-masked normal hearers. In these cases, the performance of the noise-masked normal hearers and the hearing-impaired subjects was considered to be equal. Using this definition of equality of performance, examination of
individual subtest scores in the remaining panels of Fig. 4 indicates that it is generally the case that the hearing-impaired subject outperforms the noise-masked normal hearers. The exceptions are subtests 1 and 6 (subtest number is indicated by the numbers at the bottom of each panel). On these two subtests there appears to be little difference between the performance of the impaired subject and the masked normals.

Figure 5 displays a similar set of performance-intensity functions for another hearing-impaired subject (HI-04) that tended to outperform the noise-masked normal hearers. Although the overall NST performance of the impaired listener, shown in the lower right panel, is consistently superior to that of the normals listening in noise, this is not the case for all individual subtests. Using the criterion of "sameness" defined previously, performance of the impaired subject is similar to that of the noise-masked normals for subtests 3, 7, 11, and 2. In no case, however, does this impaired listener perform worse than the entire group of noise-masked normal listeners.

Figures 6 and 7 show comparable data for the remaining two hearing-impaired subjects, HI-03 and HI-02, respectively. In both cases, the data in the lower right panel indicate that the hearing-impaired and noise-masked normal-hearing subjects perform equivalently on the NST. This is also generally true for individual subtest scores for both subject subgroups, although there are exceptions (subtests 3, 8, 9, and 10 in Fig. 6 and subtests 1, 2, and 8 in Fig. 7). These exceptions, moreover, are not consistently in the same direction. On some subtests the impaired subject performed better than the noise-masked normal hearers whereas on others just the opposite outcome was observed.

Throughout this analysis it has been assumed that individual subtest scores from individual subjects are reliable. Only limited data are available regarding the reliability of individual NST subtest scores obtained from individual listeners (Dubno and Dirks, 1982). Subtest-score reliability measured previously, moreover, was assessed using repetitions of a single subtest comprised of 7–9 test items. In the present study, a single subtest score was based on between 42 and 54 test items. Recall that in the present study, subtest scores obtained from hearing-impaired subjects that fell between 20% and 50% correct were retested. These same subtests were subsequently retested for the corresponding noise-masked normal hearers. As mentioned previously, this was done to increase the sample size for subsequent analysis of confusion patterns, an analysis that will not be reviewed here. In addition, some subtest scores outside these limits for the lowest two presentation levels were arbitrarily selected for retest. These data, therefore, afforded an opportunity to examine the reliability of the individual subtest scores obtained in this study. Figure 8 shows the test–retest scores for the various subtests, each represented by a different symbol. Individual data from noise-masked normal hearers and impaired listeners are presented together in this figure. Due to the randomization of presentation level in this study, the amount of practice on the NST between test and retest varied between 1 and 3 h. The data in this figure suggest that the individual subtest scores are reliable. The Pearson- \( r \) correlation coefficient between test and retest score was 0.89 (\( p < 0.01 \)). Again, each subtest score in this figure was based on 42 to 54 syllable presentations (7–9 syllables per subtest repeated six times).

The results were analyzed further to provide some insight into the types of errors made by hearing-impaired and noise-masked normal-hearing subjects. This was accomplished by examining individual subtest scores. Subtests 1–3 contain syllable-initial consonants paired with the vowel /a/. The remaining six subtests incorporated in this study all contain syllable-final consonants, two paired with /a/ (subtests 6 and 7), two paired with /i/ (subtests 8 and 9) and two paired with /u/ (subtests 10 and 11). Comparison of subtest-score profiles between the hearing-impaired subjects and their noise-masked normal-hearing counterparts would
provide some information regarding differences in the types of errors made.

To evaluate the pattern of errors made across subtests of the NST, the subtest scores in Figs. 4-7 were converted to difference scores in which the score of a given noise-masked normal hearer was expressed relative to that of the hearing-impaired subject. Specifically, \( \Delta P(c)_i = P(c)_{MNj} - P(c)_{HI} \), where \( P(c)_i \) = percent correct on subtest \( i \), \( MNj \) = masked normal \( j \), and \( HI \) = hearing impaired listener.

Figure 9 displays the mean \( \Delta P(c) \) values obtained for each of the four subgroups of subjects, with each panel representing data from a different subgroup. The three symbol types reflect the three speech presentation levels employed.

A separate analysis of variance with repeated measures having within-subject factors of presentation level (three levels) and subtest (nine subtests) was performed on the data in each panel of Fig. 9. For subgroups HI-02 and HI-03, the grand mean \( \Delta P(c) \) was not significantly different from zero \((p > 0.10)\). That is, collapsed across levels and subtests, there was no difference in performance between the noise-masked normals and the hearing-impaired listener in these two subgroups. For subgroups HI-01 and HI-04, however, there was a significant difference between the performance of the impaired listener and the noise-masked normal hearers, with the impaired subject outperforming the normal hearers listening in noise \((p < 0.01)\). For all four subgroups, there was a significant effect of subtest \((p < 0.01)\) on \( \Delta P(c) \), whereas presentation level was not significant \((p > 0.05)\). In addition, the subtest-by-level interaction was significant in all four subgroups \((p < 0.01)\). The significant main effect of subtest and the significant subtest \( x \) level interaction suggest that the relative error rates across subtests were not the same for the noise-masked normals and the hearing-impaired listeners and that the manner in which their performance differed across subtest varied with presentation level.

III. DISCUSSION

Regarding overall nonsense-syllable recognition, none of the hearing-impaired subjects in this investigation performed worse than the corresponding noise-masked normal hearers. When there was a difference in performance, the hearing-impaired subjects performed better than their normal-hearing counterparts listening in noise. This outcome occurred for two of the four hearing-impaired subjects with the other two subjects performing the same as their respective subgroups of masked normals.

Prior studies of speech recognition using noise-masked normal hearers for comparison to hearing-impaired subjects have also reported mixed outcomes. Milner (1982), for example, presents performance-intensity functions from two listeners with sensorineural hearing loss listening to unfiltered and filtered nonsense syllables. Only the unfiltered data are appropriate for comparison to the data from the present study. For subjects having unilateral sensorineural impairment, comparison was made to two sets of data from noise-masked normal ears. In one case, the listener's own normal ear served as the noise-masked normal ear, while in the other case a second subject was the noise-masked nor-
mal. For both comparisons, the scores obtained for the simulated loss were 20%-25% better than those obtained for the actual loss at all presentation levels. For the other impaired subject in Milner's study, mixed results were obtained when compared to the data from a noise-masked normal hearer. At speech levels below 80 dB SPL, performance of the hearing-impaired subject exceeded that of the masked normal by 15%-20%, whereas the opposite was true for levels exceeding 80 dB.

More recently, Braida et al. (1985) and Zurek and Delhorne (1986) have reported good agreement between speech-recognition scores of hearing-impaired subjects and comparable data from noise-masked normals. All subjects in these two studies, however, listened to speech in a background of broadband noise, whereas Milner (1982) tested his subjects in quiet.

In another recent study, Fabry and Van Tasell (1986) reported data from six unilaterally impaired listeners in which the listener's own normal ear served as the noise-masked normal ear for comparison. All three possible outcomes were observed in this study when recognition scores from the ears with simulated and actual hearing loss were compared. The noise-masked normal ear for a given subject yielded scores, obtained at two presentation levels, that were either better than, the same as, or worse than the scores from the impaired ear. One of the levels used (90 dB SPL) was the same for all subjects and was comparable to the highest level used with three of the four subgroups of this study (86 dB SPL). For this high level presentation, the difference in overall percent correct between the impaired ear and the masked ear in the Fabry and Van Tasell study had a mean value of −7.4% and a range of −1.3% to −23.3% with negative values indicating $P(c)_A < P(c)_M$. The mean performance difference at 86 dB in the present study for subtests using CV syllables paired with o/, u/, and i/ is from +26.3% to −26.3%. Thus, for similar stimuli, the results of both studies are similar with noise-masked normal listeners tending to outperform the corresponding hearing-impaired listener. Milner (1982) reached a similar conclusion using CV items paired with o/, u/, and i/. When the difference in performance between masked and impaired ears at 86 dB is examined across all subtests from the present study, including VC syllables paired with o/, u/, and i/, the mean difference becomes +6.3% and the range is +21% to −15%. For this broader range of stimuli, the tendency is for the hearing-impaired subject to outperform normal hearers listening in noise.

The findings of the present study are consistent with the limited data available in the literature for comparable test conditions. Because of the diversity of outcomes in the literature, however, virtually any finding would have been consistent with at least some prior data. The diversity of previous outcomes appears to be due, in part, to the nature of the CV or VC nonsense syllables selected for testing. The reasons for this dependence of the goodness of the match in performance on the consonant location within the syllable are not immediately obvious. It is advisable, therefore, to include as many vowel contexts and consonant positions as possible before drawing conclusions regarding the accuracy of the match obtained between the speech-recognition performance of masked normals and hearing-impaired listeners. This would also add greater face validity to the measure of "speech recognition."

The outcome of the present study regarding the utility of the noise-masked normal ear as a model of sensorineural hearing loss is equivocal. For two of the four hearing-impaired subjects of this study, overall speech-recognition performance could be accurately simulated by introducing a spectrally shaped masking noise into a normal ear. For the remaining two subjects, this was not the case. It is important to note, however, that the four impaired subjects of this study never performed worse than the noise-masked normal hearers. This is true for overall speech-recognition performance sampled with a wide variety of speech stimuli and over a wide range of speech levels, extending from conversational levels to levels approaching those experienced with amplification. This is true, moreover, despite closely matching the impaired and noise-masked listeners for audibility of the speech signal. If additional secondary psychoacoustic processing deficits were operating in the four impaired subjects of this study, one would have expected them to perform worse than noise-masked normal hearers listening under the same test conditions. Again, such an outcome was not observed in the present study, suggesting that either the four impaired subjects of this study did not have such secondary processing deficits or, if they did, the deficits exerted no influence on overall speech-recognition performance. Not having obtained additional psychoacoustic measures from these subjects, it is not possible to decide between these two alternatives.

ACKNOWLEDGMENTS

This work was supported in part by an RCDA awarded to the first author by the National Institute of Neurological, Communicative Disorders and Stroke (NINCDS) and an NINCDS grant awarded to U.C.L.A. Preparation of the manuscript was also supported, in part, by a grant from NINCDS to Indiana University. The authors thank Richard Tyler and Dianne Van Tasell for providing helpful comments on earlier versions of this manuscript.

1With the multifilter set to 0 dB at each 1/3-octave band (attenuation range is from +25 to −25 dB at each frequency), the SPL output was measured at each 1/3-octave band in a 6-cm2 coupler for a broadband noise input signal. The 1/3-octave bands are equal to or greater than the critical band, thereby enabling use of the critical ratio to produce an estimated masked threshold at each center frequency. This was accomplished by converting the overall sound pressure level for a given 1/3-octave band into noise spectrum level, $L_{N}$. If the overall dB SPL = overall dB SPL = 10 log (1/3-octave bandwidth). The critical ratio was then added to $L_{N}$. Thus, for a flat 0-dB setting of the multifilter, a predicted masked threshold was estimated at each 1/3-octave center frequency. Adjusting the overall level of the masking noise affected the masked thresholds uniformly across 1/3-octave bands, while each band could also be adjusted separately over a 50-dB range (+25 to −25 dB re:0-dB measurements).