Speech Identification Difficulties of Hearing-Impaired Elderly Persons: 
The Contributions of Auditory Processing Deficits

Larry E. Humes
Laurel Christopherson
Audiology Research Laboratory
Department of Speech and Hearing Sciences
Indiana University, Bloomington

This study examined the performance of four subject groups on several temporally based measures of auditory processing and several measures of speech identification. The four subject groups were (a) young normal-hearing adults; (b) hearing-impaired elderly subjects ranging in age from 65 to 75 years; (c) hearing-impaired elderly adults ranging in age from 76 to 86 years; and (d) young normal-hearing listeners with hearing loss simulated with a spectrally shaped masking noise adjusted to match the actual hearing loss of the two elderly groups. In addition to between-group analyses of performance on the auditory processing and speech identification tasks, correlational and regression analyses within the two groups of elderly hearing-impaired listeners were performed. The results revealed that the threshold elevation accompanying sensorineural hearing loss was the primary factor affecting the speech identification performance of the hearing-impaired elderly subjects both as groups and as individuals. However, significant increases in the proportion of speech identification score variance accounted for were obtained in the elderly subjects by including various measures of auditory processing.

KEY WORDS: speech identification, elderly, hearing impaired, auditory processing

Hearing impairment is the third most prevalent chronic disability identified by those over the age of 65 (NCHS, 1977). In addition, disabilities involving communication are considered by the elderly to be of greatest consequence (Jacobs-Condit, 1984). With the prevalence of hearing loss at 25-40% for individuals over 65 years of age (Herbst, 1983; NCHS, 1977, 1986), deficits in speech understanding associated with hearing loss represent the major component of elderly people's communication disability. The research described here seeks to gain a better understanding of the hearing-related speech identification deficits experienced by this rapidly growing segment of society.

Evaluation of the speech understanding problems of the elderly is difficult because speech understanding in normal-hearing young adults is itself a complex process. Because the peripheral portion of the auditory system, especially the cochlea and auditory nerve, are known to deteriorate with age, examination of age differences in the peripheral encoding process is a logical place to begin an investigation of the factors underlying the speech recognition problems experienced by the elderly. The most obvious and well-documented peripheral deficit in the elderly is the presence of a high-frequency sensorineural hearing loss (e.g., Bunch, 1929, 1931; Corso, 1959; Spoor, 1967). We have demonstrated recently that this peripheral loss of hearing sensitivity can account for much of the difficulty that hearing-impaired elderly persons experience in understanding speech (Humes & Roberts, 1990). In that study, approximately 80% of the variance in speech identification performance could be accounted for by variations in average hearing loss. A similar conclusion was reached
recently by Helfer and Wilber (1990). In addition, Humes and Roberts demonstrated that young adults with a simulated hearing loss, matching that of the hearing-impaired elderly subjects, performed the same as the elderly subjects with actual hearing loss on a speech identification task for a wide variety of listening conditions. This further supports the conclusion that the primary factor underlying the speech identification problems of hearing-impaired elderly persons is their peripheral loss of hearing.

In both the study by Humes and Roberts (1990) and the study by Helfer and Wilber (1990), however, the subjects ranged in age from about 65 to 75 years. This age group is frequently referred to in the literature on aging as the "young old." In the present study, we evaluated the contributions of audibility to speech identification performance in both the "young old" and the "old old," the latter group comprising individuals in the age range 76–86 years. As in the study by Humes and Roberts (1990), we pursued both a correlational within-group approach and a between-group approach to this problem. For the between-group comparisons, one of the groups was again composed of normal-hearing young adults with simulated hearing loss matching that of the elderly subjects, and the two age groups of elderly subjects were matched for average hearing loss.

The other primary issue examined in this study was the contribution of other auditory processing deficits to the speech understanding problems of hearing-impaired elderly persons. Even with the younger elderly subjects, 20–25% of the variance in speech understanding scores cannot be accounted for by the hearing loss (Helfer & Wilber, 1990; Humes & Roberts, 1990). Perhaps deficits in auditory processing can explain some of the residual variance. Although there are many ways in which an auditory processing deficit might be defined, in this study we have defined it as difficulty in distinguishing between two minimally contrasted acoustic stimuli. That is, can listeners discriminate between a standard acoustic stimulus and a comparison stimulus that differs from the standard along a single stimulus dimension, such as stimulus frequency, intensity, duration, and so forth?

Deficits in auditory processing were assessed in this study using a battery of psychoacoustic discrimination tests referred to as the Test of Basic Auditory Capabilities (TBAC) (Watson, Jensen, Foyle, Leek, & Goldgar, 1982; Watson, Johnson, Lehman, Kelly, & Jensen, 1982). This battery of tests assesses a wide range of auditory discrimination skills, has extensive normative data available, and yields performance measures from hearing-impaired listeners that do not appear to be correlated with the amount of sensorineural hearing loss (Espinoza-Varas & Watson, 1986). Thus, performance on this battery of tests afforded an opportunity to examine that portion of the variance in speech identification scores due to auditory-processing deficits unconfounded by variations in hearing sensitivity.

**Method**

**Subjects**

Four groups of subjects participated in this experiment: (a) young normal-hearing adults (N = 10) aged 19–36 years (M = 23.6 years); (b) elderly hearing-impaired subjects (N = 13) 65–75 years (M = 69.7 years); (c) elderly hearing-impaired subjects (N = 10) aged 76–86 years (M = 79.8 years); and (d) young normal-hearing adults (N = 12), aged 20–31 years (M = 22.1 years), with a hearing loss simulated by the introduction of a spectrally shaped masking noise into the test ear. Criteria for normal and impaired hearing were as follows. All normal-hearing young adult subjects had normal hearing [pure-tone air-conduction thresholds < 20 dB HL (ANSI, 1969) from 250 to 8000 Hz] and normal immittance measurements (normal tympanograms and acoustic reflexes present in response to contralateral presentation of a 100-dB HL 1000-Hz tone) bilaterally. All hearing-impaired elderly subjects had bilaterally symmetrical (interaural threshold differences < 20 dB at all frequencies, typically < 15 dB) sloping high-frequency sensorineural hearing loss attributable to presbycusis, and normal immittance measurements (as defined above). All subjects were in good health and were native speakers of English.

All subjects were tested monaurally with the better ear selected as the test ear in the elderly hearing-impaired subjects and the test ear randomly determined for the young adults. The mean air-conduction thresholds of the test ears of the impaired subjects are shown in Figure 1. The masked thresholds of 3 normal-hearing young adults with simulated hearing loss are also provided in this figure for comparison. There is good agreement between the thresholds of the listeners with actual loss and those with simulated hearing loss.

**Materials/Apparatus**

Two sets of taped materials were presented to all subjects; one was a series of basic auditory processing tests referred to as the Test of Basic Auditory Capabilities (TBAC) (Watson,
The TBAC is a battery of eight tests of auditory processing developed from a large-scale analysis of a much broader range of auditory processing tasks (Johnson, Watson, & Jensen, 1987). All the tests are administered in the same fashion through use of the standard two-alternative forced-choice paradigm. In this paradigm, three successive stimulus samples are presented on each trial. The first stimulus presentation is always the standard stimulus to which each of the next two stimuli in the trial is compared. The subject's task is to determine which of the last two stimuli differs from the standard stimulus. For each task the discrimination progresses from an easy discrimination that nearly every subject can make to a difficult one that very few subjects can make. The step sizes between these two extremes vary across tasks to produce 8-point psychometric functions with a constant-stimulus method and to yield overall percent-correct scores of 75–90% in normal-hearing young adults. Three of the TBAC tests measure a listener's ability to discriminate pure tones differing in frequency (df), intensity (di), or duration (dT). All three tasks make use of a 1000-Hz pure tone as the standard stimulus. Another test in the TBAC measures a listener's ability to discriminate differences in the rhythm of a series of tone pulses (dTP). The standard stimulus consists of a train of six 20-ms 1000-Hz tone pulses, separated by an interstimulus interval of 40 ms. Alternate interpulse intervals are decreased in one of the two comparison stimuli, resulting in the perception of a different rhythm for suprathreshold changes in interpulse interval. The fifth test, referred to as the embedded test-tone paradigm (ET), requires subjects to discriminate changes in the duration of a component occurring in the middle of a 10-tone sequence. The sixth and seventh tests of the TBAC are two tests of discrimination of temporal order, one using tones (TO) and the other a sequence of syllables (SS). In both paradigms, the standard stimulus consists of a sequence of four sounds, either tones of differing frequency or different consonant-vowel syllables. In one of the two comparison intervals, the order of the middle two sounds is reversed. The difficulty of this task is varied on the tapes by changing the duration and presentation rate of the four-sound sequence making up the stimulus. The final test included in the TBAC is a speech identification task (SI) in which subjects are presented with nonsense syllables from three subtests of the NST and are asked to select the syllable heard from among the set of three alternatives provided for each stimulus. The difficulty of this task is manipulated by varying the level of a broad-band background noise.

The experimental tapes were played back through a two-channel cassette tape deck (Sansui, D-W9). The output of this tape deck was routed to a two-channel amplifier (McIntosh, C24) and delivered to a network of 13 pairs of matched TDH-39 earphones mounted in MX-41/AR cushions.

The spectrally shaped masking noise used to simulate the sensorineural hearing loss of the elderly hearing-impaired listeners was generated as follows. The output of a random-noise generator (Grason Stadler, 1390-B) was shaped by a 1/3-octave-band equalizer (Industrial Research Products, TEQ DG-4023), amplified (Crown, D-75), and sent to one input of a custom-made mixer. The output of a second random-noise generator (Grason Stadler 901B) was routed through a high-pass filter (Kemo, VBF-25MD), having a cut-off frequency of 3.7 kHz and a rejection rate of 135 dB/octave, amplified (Crown, D-75), and sent to another input of the custom-made mixer. The output of the mixer was then sent to the input of a digital audio tape recorder (Panasonic, SV-3500). On playback, the output of this tape deck was routed through the same amplifier used for the speech testing. Before recording the spectrally shaped noise on the digital tape, the octave band levels required to produce masked thresholds equivalent to the quiet thresholds of the elderly hearing-impaired subjects were calculated using the critical ratio. Acoustically measured octave-band levels were then adjusted to achieve these target values by manipulating the controls of the 1/3-octave equalizer and the amplifiers. Masked pure-tone thresholds were measured in three normal-hearing young adults using the same clinical procedures with which the quiet thresholds were obtained from the elderly hearing-impaired listeners. As was noted previously, the mean masked thresholds obtained in the presence of the spectrally shaped noise appear as the unfilled circles in Figure 1. The masked thresholds are in general agreement with the mean quiet thresholds of the elderly hearing-impaired listeners. The individual thresholds of the three noise-masked normal listeners never differed by more than 5 dB at any frequency. The spectrally shaped noise was then recorded and mixed with the test signal during speech recognition and TBAC testing for those subjects with simulated hearing loss.

**Procedure**

Following screening and audiologic testing, the subjects were presented the TBAC materials and the NST materials over headphones at a level of 75 dB SPL. Multiple-choice answer forms were provided for each test, and all responses were collected using a pencil-and-paper format. The TBAC contains taped instructions and several practice items to
familiarize the listeners with the task prior to testing. All testing was completed in a large acoustically treated sound room with noise levels less than those required for threshold measurements with headphones (ANSI, 1977). Approximately 2 hours were required for the subjects to complete the testing in this experiment. All subjects were paid for their participation, and none had participated previously in similar testing.

Results and Discussion

The mean percent-correct scores on the TBAC are provided in Figure 2 for each of the four groups of subjects in this study. Figure 3 contains the mean speech identification scores of each of the subject groups and for the three listening conditions examined. The mean values from Figures 2 and 3, together with the standard deviations, are provided in Table 1.

Examination of the standard deviations in Table 1 across groups reveals that subjects in the two elderly hearing-impaired groups were much more variable than the two younger groups of subjects. Because of the lack of homogeneity of variance required for analyses of between-group differences with parametric statistics, nonparametric statistics were used for these analyses. Kruskal-Wallis one-way analyses of variance (Kirk, 1968), summarized in Table 2, were performed for all auditory processing and speech identification measures. A significant effect (p < .01) of subject group was observed for all measures in Table 2, except duration discrimination (dT). Post hoc testing was then performed for each measure with the Mann-Whitney U statistic adjusted for an experimentwise significance level of p < .05 (Kirk, 1968). The two groups of hearing-impaired elderly listeners performed significantly (p < .05) worse than the other subject groups on four of the eight TBAC tests: the frequency discrimination task, the embedded test-tone task, temporal order for tones, and temporal order for syllables (the syllable-sequence test). On these same four tasks, there were no differences in performance between the two young groups or between the two elderly hearing-impaired groups. This pattern of results suggests that the significant performance decrements observed for the latter two groups are due to aging, the presence of actual cochlear pathology, or the interaction of these two factors. If audibility alone were the factor underlying this pattern of results for these four TBAC tests, then the performance of the young noise-masked normal listeners would not be significantly different from that of the two groups of elderly hearing-impaired listeners.
TABLE 1. Means and standard deviations of percent-correct scores on the eight tests of the Test of Basic Auditory Capabilities (TBAC) and the three versions of the Nonsense Syllable Test (NST).

<table>
<thead>
<tr>
<th>Subject group</th>
<th>Test</th>
<th>Young NH</th>
<th>M</th>
<th>SD</th>
<th>HI (65–75 years)</th>
<th>M</th>
<th>SD</th>
<th>HI (76–86 years)</th>
<th>M</th>
<th>SD</th>
<th>Young SHL</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TBAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dF</td>
<td>86.5</td>
<td>9.3</td>
<td>69.0</td>
<td>12.2</td>
<td>64.7</td>
<td>23.7</td>
<td>82.2</td>
<td>6.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dl</td>
<td>93.0</td>
<td>7.2</td>
<td>78.9</td>
<td>14.3</td>
<td>70.3</td>
<td>19.5</td>
<td>80.4</td>
<td>7.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dT</td>
<td>83.5</td>
<td>7.7</td>
<td>76.2</td>
<td>11.2</td>
<td>67.4</td>
<td>19.3</td>
<td>74.3</td>
<td>7.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dTP</td>
<td>86.7</td>
<td>5.7</td>
<td>79.0</td>
<td>9.5</td>
<td>66.9</td>
<td>14.0</td>
<td>79.6</td>
<td>5.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ET</td>
<td>77.8</td>
<td>8.1</td>
<td>69.0</td>
<td>6.8</td>
<td>55.3</td>
<td>22.5</td>
<td>79.0</td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TO</td>
<td>81.2</td>
<td>5.8</td>
<td>72.0</td>
<td>7.7</td>
<td>59.3</td>
<td>22.6</td>
<td>82.6</td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>67.3</td>
<td>13.8</td>
<td>51.4</td>
<td>7.3</td>
<td>34.2</td>
<td>23.5</td>
<td>73.1</td>
<td>8.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SI</td>
<td>75.0</td>
<td>5.9</td>
<td>48.0</td>
<td>11.0</td>
<td>30.4</td>
<td>16.0</td>
<td>45.0</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unfiltered</td>
<td>98.7</td>
<td>1.7</td>
<td>65.6</td>
<td>20.9</td>
<td>52.6</td>
<td>13.8</td>
<td>69.2</td>
<td>8.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filtered</td>
<td>82.8</td>
<td>2.5</td>
<td>55.1</td>
<td>18.9</td>
<td>33.7</td>
<td>18.3</td>
<td>60.6</td>
<td>5.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filtered +</td>
<td>65.5</td>
<td>4.2</td>
<td>31.6</td>
<td>13.6</td>
<td>14.3</td>
<td>12.7</td>
<td>36.7</td>
<td>5.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>reverberation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. NH = normal hearing; HI = hearing impaired; SHL = simulated hearing loss; dF = frequency discrimination; dl = intensity discrimination; dT = duration discrimination; dTP = tone-pulse or rhythm discrimination; ET = embedded test-tone task; TO = temporal order for tones; SS = syllable sequence or temporal order for speech; SI = syllable identification.

The post hoc testing of group differences on the tone-pulse or rhythm discrimination task and the four measures of speech identification performance, including the speech identification task of the TBAC, revealed the following pattern of results. For all five measures, the young normal-hearing subjects outperformed the other three groups of subjects. In addition, the young noise-masked normal listeners did better on all four tasks than the oldest group of hearing-impaired subjects, but there were no differences in performance between the young listeners with simulated hearing loss and the youngest group of hearing-impaired elderly listeners. This pattern of results suggests that audibility is the primary factor underlying the observed performance decrements of the younger group of elderly hearing-impaired subjects. For the speech identification measures, this observation is consistent with previous findings of Helfer and Wilber (1990) and Humes and Roberts (1990). For the older group of hearing-impaired elderly listeners, however, this does not appear to be the case. The young listeners with simulated hearing loss and, therefore, comparable audibility, outperformed the group of "old old" hearing-impaired listeners. The old old subjects, therefore, appear to have rhythm discrimination and speech identification deficits beyond those explained by audibility alone. In addition, on the two speech identification tasks using filtered speech, the old old listeners also performed significantly worse than the young old subjects, despite their equivalent hearing loss. This would appear to be strong evidence for an effect of aging or an aging-by-pathology interaction on the identification of filtered speech.

The post hoc testing also revealed a unique pattern of results for intensity discrimination. The only significant differences in performance on this task were between the young normal-hearing subjects listening in quiet and all other groups of subjects, with the former outperforming the latter. This appears to represent a simple effect of audibility on intensity discrimination.

In making the between-group comparisons, we felt it was critical that the three groups with actual or simulated hearing loss have very similar amounts of hearing loss. As was noted previously, the audiograms in Figure 1 attest to the close match in average hearing loss achieved among these three groups. An important difference among these three groups, however, has to do with the individual variability in hearing loss within each group. The hearing loss was simulated in the young listeners, for example, by giving all subjects a hearing loss equivalent to the average loss of the elderly subjects. Thus, there was very little variation in hearing loss from subject to subject within this group. The elderly groups of subjects, on the other hand, although they had the same

TABLE 2. Summary of Kruskal-Wallis one-way ANOVAs examining the effects of subject group on Test of Basic Auditory Capabilities (TBAC) and Nonsense Syllable Test (NST) scores.

<table>
<thead>
<tr>
<th>Test</th>
<th>Chi-square</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency discrimination (dF)</td>
<td>17.1</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Intensity discrimination (dl)</td>
<td>15.2</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Duration discrimination (dT)</td>
<td>10.2</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Rhythm discrimination (dTP)</td>
<td>16.2</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Embedded test-tone task (ET)</td>
<td>15.2</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Temporal order-tones (TO)</td>
<td>19.3</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Syllable sequence (SS)</td>
<td>27.7</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Syllable identification (SI)</td>
<td>27.6</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>NST—unfiltered</td>
<td>26.9</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>NST—filtered</td>
<td>31.7</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>NST—filtered + reverberation</td>
<td>28.5</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>
average hearing loss, had much larger individual differences in hearing loss. As a consequence, use of a fixed sound pressure level for stimulus presentation in this study resulted in large variations in the sensation level of the stimuli for the two groups of elderly listeners. Some elderly listeners received the stimuli at lower sensation levels than any of the young listeners with simulated hearing loss. It is possible, therefore, that the observed group differences on various tests of the TBAC could be due to the poor performance of those elderly subjects who received the stimuli at sensation levels lower than the younger listeners with simulated hearing loss.

To examine this possibility, we had 6 of the 13 subjects in the younger elderly group return for retest. These 6 subjects had hearing losses (pure-tone average for 500, 1000, and 2000 Hz) poorer than the group mean and consequently received the TBAC stimuli at lower sensation levels than the young listeners with simulated hearing loss. The stimulus levels at retest were individually increased to replicate the average sensation level used with the young listeners with simulated hearing loss. A repeated-measures ANOVA was performed on the results for each TBAC test. A marginally significant improvement in performance was observed only for the syllable identification task of the TBAC ($F(1,5) = 10.04, p = .025$). It is not too surprising that performance on this speech identification task would improve at higher stimulus levels. On the basis of the results from these 6 listeners, as well as the lack of significant correlations between hearing loss and TBAC scores (described below), it is concluded that the observed group differences between young listeners with simulated loss and elderly listeners with actual loss are not due to the use of a wider and lower range of sensation levels in the two elderly groups.

In addition to the analyses of between-group effects, the data from the two elderly hearing-impaired groups were pooled ($N = 23$) for a variety of correlational and regression analyses. First, as in previous applications of the TBAC to hearing-impaired listeners (Espinoza-Varas & Watson, 1986), we found no significant correlations between measures of hearing loss and individual TBAC test scores, except for the syllable identification test. A significant ($p < .01$) negative correlation of $-0.80$ was observed between performance on this TBAC test and hearing loss. Measures of hearing loss included in the correlational analyses consisted of individual pure-tone thresholds at 500, 1000, 2000, and 4000 Hz, and three different pure-tone averages (thresholds averaged at 500, 1000, and 2000 Hz; at 1000, 2000, and 4000 Hz; and at 500, 1000, 2000, and 4000 Hz).

Significant ($p < .01$) negative correlations, varying from $-0.70$ to $-0.85$, were observed between the four-frequency or high-frequency (1000, 2000, 4000 Hz) pure-tone averages and performance on the NST for all three listening conditions. Although these correlations suggest that 50-65% of the variance in speech identification score is associated with individual variations in hearing loss, this is a considerably lower figure than has been observed previously in groups of young elderly listeners aged 65–75 years (Helfer & Wilber, 1990; Humes & Roberts, 1990). When we recalculated the correlation coefficients for those elderly subjects in the 65–75 year age range ($N = 13$), however, the correlations between hearing loss and speech identification score ranged from $-0.80$ to $-0.90$ across the various measures of speech identification. These values are in good agreement with previous studies using subjects of comparable age.

Significant ($p < .01$) positive correlations, ranging from 0.81 to 0.90, were also observed among the various measures of speech identification performance measured with the NST. Thus, those listeners who had difficulty with unfiltered speech in quiet also had difficulty with filtered speech, both with and without reverberation.

The final correlational analysis examined the relation between age and the various test scores for both the TBAC and the NST. Significant ($p < .01$) negative correlations of moderate strength, ranging from $-0.59$ to $-0.67$, were observed between age and performance on the two filtered NST tests, the rhythm discrimination task of the TBAC, and both of the temporal-order tests of the TBAC (tones and syllables). The older the subject, the poorer the performance on these tasks. Consistent with these correlations, recall that the between-group analyses of the two filtered speech identification measures indicated that the older group of elderly subjects performed more poorly than all the other groups on most of these tasks.

Regression analyses were also performed on the data with each of the three scores on the NST serving, in turn, as the predicted variable. Predictor variables included age, scores for each of the eight tests of the TBAC, and various measures of hearing loss, including thresholds at individual frequencies and three- and four-frequency pure-tone averages. The results are summarized in Table 3. For all three measures of speech identification, a measure of average hearing loss was entered on the first step of the stepwise multiple regression analyses. For unfiltered speech, slightly more than 70% of the variance in the speech identification task could be accounted for by variations in average hearing loss (pure-tone average for 1000, 2000, and 4000 Hz). For the two measures of filtered speech identification, the four-frequency pure-tone average was entered on the first step and accounted for 51–55% of the variance in speech identification scores. The high-frequency pure-tone average (1000, 2000, and 4000 Hz), however, accounted for only 1–2% less variance than the four-frequency average for each of these measures.

Ninety-five percent of the variance in NST scores for unfiltered speech could be accounted for by the addition of scores from three TBAC tests: duration discrimination, fre-
frequency discrimination, and the embedded test-tone task. The addition of scores on the TBAC frequency discrimination task also resulted in a considerable increase in the proportion of variance accounted for in the speech identification scores for filtered speech.

Finally, adding age as a predictor variable increased the variance accounted for on the speech identification task for filtered reverberant speech by 12%. Note, however, that the full set of predictor variables for filtered reverberant and nonreverberant speech could account for only 62–67% of the variance in speech identification performance. This is considerably less than the 95% variance accounted for with the unfilted speech materials.

In summary, the between-group comparisons, the correlational analyses, and the regression analyses converge on a similar conclusion: The primary factor underlying the speech identification difficulties of the hearing-impaired elderly is their sensorineural hearing loss. It is also apparent in the current study, however, that this is less true for the listeners over age 75. For half of the between-group comparisons of speech identification performance, this group of subjects performed significantly worse than all three of the other groups, two of which had similar amounts of hearing loss, either actual or simulated. The correlational and regression analyses, moreover, support an effect of age on speech identification performance, independent of the effects of hearing loss, especially for filtered reverberant speech. It has been suggested previously that elderly persons may be particularly vulnerable to the negative effects of reverberation (CHABA, 1988; Duquesnoy & Plomp, 1980; Nabelek & Robinson, 1982).

It is interesting that all four of the TBAC tests for which the two groups of elderly listeners performed significantly worse than the younger listeners (some of which are significant predictors of their speech identification performance for unfiltered speech) involve various aspects of temporal processing. Three of the four tasks, for example, are the embedded test-tone task, temporal-order discrimination for pure tones, and temporal-order discrimination for syllables (syllable-sequence task). Moreover, the fourth task, frequency discrimination for a midfrequency pure tone, might also be considered to be a timing-based phenomenon (Moore, 1989).

Age-related deficits in temporal processing, especially the temporal sequencing of acoustic signals, have also been reported recently by Trainor and Trehub (1989). Using low- and midfrequency stimuli that were well within the normal-hearing region of their elderly subjects, these investigators observed significant differences between a young and an old (approximately 65–75 years of age) group of subjects in the identification and discrimination of tonal sequences with contrasting order. Group differences were not affected by changes in the speed of presentation or the amount of practice. The present findings regarding age-related deficits on the temporal-order tasks of the TBAC confirm and extend the observations of Trainor and Trehub (1989). These investigators also speculated, however, that the observed age-related temporal-order deficits might underlie some of the speech understanding difficulties of these same elderly listeners. The results of the regression analyses in the present study do not support a strong linkage between individual differences in the temporal order and speech identification tasks. It is possible, however, that a stronger relation between these two measures could be observed for other measures of speech understanding, such as meaningful sentences or continuous discourse spoken at various rates. Age-related deficits in frequency discrimination ability have also been observed previously (Abel, Krever, & Alberti, 1990; Konig, 1957). Both of the elderly hearing-impaired groups in this study demonstrated significantly poorer frequency discrimination performance than the two younger groups of subjects. Moreover, in the present study, individual differences in frequency discrimination ability accounted for 8–11% of the individual variability in the identification of nonreverberant speech.

Acknowledgments

This work was supported, in part, by grants from the National Institute on Aging. We thank the subjects for their willing participation in this project.

References


Received July 9, 1990
Accepted September 28, 1990

Requests for reprints should be sent to Larry E. Humes, PhD, Department of Speech and Hearing Sciences, Indiana University, Bloomington, IN 47405.