Can Age-Related Decline in Speech Understanding Be Explained by Peripheral Hearing Loss?

James Jerger

Abstract
Speech audiometric scores were compared across the age range from 50 to 90 years in 137 subjects selected in such a way that average audiometric thresholds were matched across four age groups. Thus any age-related changes in speech audiometric scores could not be attributed to age-related differences in peripheral hearing sensitivity. Four speech audiometric measures were studied; phonemically-balanced words (PB), Speech Perception in Noise (SPIN) test for both high- and low-predictability sentences, and the Synthetic Sentence Identification (SSI) test. There was an age trend for all four speech measures but only the change in SSI (30%) was statistically significant. The argument that the change in SSI can be explained by subtle changes in the auditory periphery, not reflected in audiometric thresholds, is weakened by the fact that the change in SSI was greater than the change in either of the two monosyllabic word tests (PB and SPIN-low). The argument that the change in SSI can be explained by concommitant cognitive decline is not supported by correlations among SSI performance and any of several neuropsychological measures of cognitive function in the same subjects. Finally, the lack of a significant interactive effect between hearing sensitivity level and cognitive status does not support a model in which a peripherally degraded speech signal interacts with a deficit in cognitive function to produce the decline in speech audiometric scores. We conclude that the observed age-related decline in SSI performance cannot be satisfactorily explained by peripheral hearing sensitivity loss.

Key Words: Aging, elderly, hearing loss, speech audiology

The effect of aging on speech audiometric scores is currently a controversial topic. Previous studies showing apparently age-related declines in performance on various speech audiometric tests (e.g., Pestalozza and Shore, 1955; Balas, 1962; Punch and McConnell, 1969; Carhart and Nicholls, 1971; Smith and Prather, 1971; Rintelmann and Schumaier, 1974; Bergman et al, 1976; Bess and Townsend, 1977; Jerger and Hayes, 1977; Bergman, 1980; Arnst, 1982; Otto and McCandless, 1982; Duquesnoy, 1983a, 1983b; Dubno et al, 1984; Wingfield et al, 1985; Martini et al, 1988) have been challenged on the basis that degree of hearing sensitivity loss has not been sufficiently controlled (CHABA Working Group on Speech Understanding and Aging [WGSUA], 1988; Willott, in press). Since high-frequency sensitivity is known to decline systematically with age, and since high-frequency sensitivity impacts many speech audiometric measures, it can be argued that the systematic decline in speech audiometric scores with age results from age-related decline in high-frequency hearing sensitivity. The WGSUA report notes that, although many studies have attempted to control for degree of audiometric loss, such studies have typically been flawed in at least three ways. Firstly, in some studies the comparison has been made between young subjects and elderly subjects whose audiometric thresholds were “within normal limits.” But if “normal limits” is defined by a screen at 20 dB HL, for example, it is possible that young adults, often in the 0 to -10 dB HL range, will have significantly better average hearing levels than elderly subjects, especially in the important high-
frequency region around 4000 Hz. Secondly, even though young and elderly subjects are matched for degree of hearing loss, it may not be appropriate to compare what may be “apples” and “oranges” in terms of the pathologic conditions underlying the impaired hearing of young and elderly persons. Thirdly, if subjects are selected over a wide range of ages and degrees of hearing loss, then the effects of age, hearing loss, and sometimes other relevant variables are confounded.

In the present paper we have attempted to re-examine this question by containing peripheral hearing sensitivity within relatively rigidly defined limits as we studied the effect of age, in the range from 50 to 90 years, on four speech audiometric measures.

METHOD

Subjects

We evaluated speech audiometric scores from a subset of 137 elderly subjects, selected from an original database of 200 elderly subjects with extensive speech audiometric results (Jerger et al, 1989). All subjects in the parent database were ambulatory, in the age range from 50 to 90 years, and in good general health. Each had volunteered to participate in a study of hearing and aging. None were clients of our hospital’s audiology service and few expressed auditory complaints.

The subset of 137 subjects was selected on the basis of the pure-tone audiometric levels of the right ear. The objective of this selection procedure was to identify a group of subjects, in each of four age ranges, with equivalent frequency-by-frequency average pure-tone hearing threshold levels. The four age groups were (1) 50 to 65 years, n = 11; (2) 66 to 70 years, n = 56; (3) 71 to 75 years, n = 54; and (4) 76 to 90 years, n = 16. There were 80 women and 57 men in the subset. The 137 subjects were selected from the larger pool in such a way that the average threshold hearing level at a particular test frequency (250, 500, 1000, 2000, 3000, or 4000 Hz) did not differ by more than 6 dB across the four age groups. The relatively smaller numbers of subjects in the 50 to 65 year group and in the 76 to 90 year group reflects the difficulty in finding younger persons with substantial loss and very elderly persons without substantial loss.

Table 1 summarizes means and standard deviations of the audiometric thresholds for right ears across the four age groups. The same data are presented graphically in Figure 1. All four age groups showed the presbyacusic audiometric pattern typically associated with aging. No one of the four age groups showed a consistently poorer pattern of sensitivity loss than any other age group. Across all four groups the average pure-tone threshold hearing level (averaged across 500, 1000, and 2000 Hz) of each individual subject ranged from 5 to 63 dB.

Procedure

Details of test selection and administration are available in a previous publication.

Table 1 Means and Standard Deviations of Audiometric Thresholds, in dB HL, in Four Age Groups

<table>
<thead>
<tr>
<th>Age Group (years)</th>
<th>Frequency in Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250</td>
</tr>
<tr>
<td>------------------</td>
<td>------</td>
</tr>
<tr>
<td>50-65</td>
<td>20 (10)</td>
</tr>
<tr>
<td>66-70</td>
<td>19 (10)</td>
</tr>
<tr>
<td>71-75</td>
<td>20 (12)</td>
</tr>
<tr>
<td>76-90</td>
<td>23 (9)</td>
</tr>
</tbody>
</table>

*The standard deviations are in parentheses.
Table 2  Means and Standard Deviations of Speech Recognition Scores, in Percent Correct, in Four Age Groups Matched for Audiometric Level

<table>
<thead>
<tr>
<th>Age Group (years)</th>
<th>Speech Audiometric Measure</th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-65</td>
<td>PB</td>
<td>92.0 (13.0)</td>
<td>60.7 (19.5)</td>
<td>97.2 (6.1)</td>
<td>94.5 (6.9)</td>
</tr>
<tr>
<td>66-70</td>
<td>SPIN-low</td>
<td>82.6 (23.6)</td>
<td>49.5 (26.0)</td>
<td>88.7 (17.2)</td>
<td>80.5 (21.9)</td>
</tr>
<tr>
<td>71-75</td>
<td>SPIN-high</td>
<td>81.5 (26.1)</td>
<td>47.0 (25.2)</td>
<td>84.8 (23.0)</td>
<td>72.2 (26.1)</td>
</tr>
<tr>
<td>76-90</td>
<td>SPIN-low</td>
<td>79.4 (19.3)</td>
<td>47.8 (21.1)</td>
<td>88.5 (10.2)</td>
<td>64.4 (21.3)</td>
</tr>
</tbody>
</table>

*The standard deviations are in parentheses.

(Jerger et al, 1989). The present analysis is based on the results of four speech audiometric test procedures.

1. Phonemically balanced word test (PB).
2. Synthetic sentence identification test (SSI).

All tests, PB, SSI, SPIN-high, and SPIN-low, were presented monotonically at a sensation level of 50 dB relative to the subject’s threshold for multi-talker babble. For PB there was no simultaneous competing message. For SSI the competing message was the continuous discourse of a single talker, presented at a message-to-competition ratio of 0 dB. For both modes of the SPIN test the simultaneous competition was multi-talker babble presented at a signal-to-babble ratio of +8 dB.

Throughout the present analysis statistical significance was evaluated at the relatively stringent alpha level of 0.01. We thought this significance level appropriate in order to minimize the likelihood that the relatively parsimonious null hypothesis (i.e., that hearing sensitivity level is a sufficient explanation for age-related decline in speech understanding) would be incorrectly rejected in this experiment.

RESULTS

For each speech audiometric measure in each age group we computed the mean and standard deviation of the performance score obtained on the right ear. These values are presented in Table 2. In addition, the means are presented graphically in Figure 2. All four of the speech measures examined showed some decline with age, but the synthetic sentence identification test (SSI) showed the largest change. Average SSI performance decreased systematically, from a high of 94 percent, in the youngest age group (50–65 years), to a low of 64 percent in the oldest age group (76–90 years), a decline of 30 percent. The other three speech measures also showed trends toward decreased performance with increasing age, but in none of these three measures did the decline exceed 15 percent. The change with age was 13 percent for both PB and SPIN-low, and 9 percent for SPIN-high.

In order to evaluate the statistical significance of these trends we first transformed all percent correct scores to their arc sine equivalents, in order to correct for skewness, then submitted the transformed data to a two-factor, split-plot analysis of variance. There was one between-subjects factor (age group) and one within-subjects factor (speech measure). This initial multivariate analysis showed a significant overall age-group effect (p = .0066) and a significant interaction between age group and speech measure (p = .0034). We carried out, therefore, individual one-factor (age group) analyses of variance separately for each of the
four speech measures. These analyses revealed that the age trend was significant only for SSI (p = .0001). For the other three speech measures, PB, SPIN-low, and SPIN-high, probabilities of alpha error exceeded 0.01. Thus the significant interaction between age group and speech measure, noted in the two-factor analysis, could be accounted for by the fact that SSI showed a significantly greater age effect than either of the other three speech measures. Further post-hoc analyses were then carried out, comparing all pairs of means within a given test. Significance was evaluated at an alpha error level of 0.01, based on Scheffe’s S procedure. For SSI this post-hoc analysis revealed that, of the six possible pairs of means, two were significantly different and four were not. Significant differences were noted when the 70 to 90 year age group was compared with the 66 to 70 year age group (p = .0051) and with the 50 to 65 year age group (p = .0003). In the case of PB, SPIN-low, and SPIN-high, there were no significant differences among any of the six pairs of means.

DISCUSSION

The present results clearly show an age-related change in performance on the synthetic sentence identification (SSI) test. The average SSI score in this sample of elderly subjects declined by 30 percent over the age range from 50 to 90 years. Can this decline be explained by age-related changes in hearing sensitivity? The present results argue against such an explanation.

Hearing sensitivity was controlled in the present sample, to the extent that such control is possible, by equating distributions of audiometric threshold levels for pure tones, including the important frequencies of 3000 and 4000 Hz (Kryter, 1983, 1988), across age groups. It can be argued, however, that aging may be accompanied by subtle changes in cochlear function not manifest in the pure-tone threshold levels. One might hypothesize, for example, that age-related changes in frequency resolution (cf. Patterson et al., 1982), not reflected in threshold sensitivity, might impact the suprathreshold coding of complex signals to an extent sufficient to affect SSI scores. The present data do not, however, provide support for such a hypothesis. If, for example, frequency resolution becomes poorer with age, then such a change in cochlear function should have maximal effect on tests like PB and SPIN-low, since spectral resolution is presumably more important for monosyllabic word recognition than for the identification of whole sentences. But neither PB nor SPIN-low showed the kinds of age effects to be expected from progressively more-impaired spectral resolution.

One might, of course, hypothesize other, as yet undiscovered, age-related changes in cochlear function, which spare pure-tone threshold sensitivity, yet have the potential to impact speech recognition scores like SSI. But a similar argument can be marshaled against all such hypotheses. Previous studies of speech audiometric scores for different types of speech materials in subjects with high-frequency hearing loss (cf. Jerger and Hayes, 1977) suggest that changes in cochlear status can be expected to have a greater effect on single-syllable word recognition than on tasks like SSI. But the present results show exactly the opposite effect: greater change in SSI than in tasks like PB and SPIN-low. It is difficult, therefore, to reconcile the present results with the hypothesis that the age-related decline in SSI can be explained by changes at the level of the cochlea.

How, then, can we explain the systematic declines in SSI scores with age? It has been suggested (Olsho et al., 1985; CHABA, 1988) that such effects might be explained by concomitant decline in one or more of the cognitive abilities important for carrying out speech recognition tasks. Arguing against this possibility, however, is the fact that our previous correlational analysis (Jerger et al., 1991), of the database from which this sample was drawn, demonstrated only a limited predictive relation between the SSI scores and any of several neuropsychological tests probing a variety of cognitive dimensions.

If neither hearing sensitivity status alone, nor cognitive function alone, can explain the phenomenon of age-related decline in speech recognition scores, then perhaps the observed decline results from an interaction between the two factors. Such an interactive model has, indeed, been proposed by Willot (in press). He suggests that what have been interpreted as changes in central auditory function may, instead, be reflections of the interaction between a speech signal degraded by peripheral pathology and a deficit in cognitive function. The stress placed on an impaired cognitive system by the peripherally degraded speech signal might adversely affect performance on speech audiometric tasks to an extent not predicted from either deficit alone. To investigate this
possibility we divided our total group in two ways; first, according to degree of peripheral hearing sensitivity loss (PTA; average of both ears at 500, 1000, 2000, and 4000 Hz), then according to a cognitive measure of speed of mental processing, the Digit Symbol subtest of the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1977). This is a complex measure of information processing and speed of manual response. Its relevance for speech audiometric procedures (Jerger et al., 1991) derives from its sensitivity as a measure of speed of mental processing. On each measure, hearing loss (HL) and digit symbol (DS) score, we divided the total group at the 50th percentile into the best half and the worst half. Thus, HL1 = 50 percent with least loss (PTA < 26 dB); HL2 = 50 percent with most loss (PTA ≥ 26 dB); DS1 = 50 percent with best digit symbol score (Raw Score > 6); and DS2 = 50 percent with poorest digit symbol score (Raw Score ≤ 6).

Next we formed four subgroups as follow: I = HL1 and DS1; II = HL2 and DS1; III = HL1 and DS2; IV = HL2 and DS2.

We then computed the average speech score for each of these four subgroups on each of the four measures of speech understanding. We reasoned that the following relations should hold:

\[ A = (I - II) = \text{cognitive effect;} \text{ i.e., difference in average speech score between best half and worst half on Digit Symbol test with degree of hearing loss held constant.} \]

\[ B = (I - III) = \text{hearing loss effect;} \text{ i.e., difference in average speech score between half with least loss and half with most loss, with Digit Symbol score held constant.} \]

\[ C = (I - IV) = \text{actual combined effect;} \text{ i.e., difference in average speech score between half with least loss and best Digit Symbol score and half with most loss and poorest Digit Symbol score.} \]

We further reasoned that an additive model would predict that \( C = (A + B) \), whereas an interactive model would predict that \( C > (A + B) \).

The actual values of \( A, B, C, (A + B), \) and \( [C - (A + B)] \) for the present data are summarized in Table 3. The final row, labeled \([C - (A + B)]\), is the interactive effect. For SSI the interactive effect was +4 percent. The other three speech measures showed similarly small effects. Indeed, for two measures (PB and SPIN-high) the effect was in the negative direction. Averaged across all four speech measures the interactive effect was +0.5 percent. These results fail to provide strong support for an interactive model of hearing loss and cognitive effects.

In summary, we have shown a progressive, age-related decline in performance on the SSI test that cannot be explained by age-related change in hearing sensitivity loss. Furthermore, this decline was demonstrated, not between two groups (one young and the other elderly), but across four age sub-groups within the elderly age range. After reviewing a number of alternative explanations, including changes in the auditory periphery not reflected in pure-tone thresholds, cognitive status, and a possible interaction between hearing sensitivity level and cognitive function, we conclude that none provides a satisfactory explanation for the observed changes in speech understanding.

Acknowledgment. This research was supported by research grant #AG05680 from the National Institute of Aging, National Institutes of Health, U.S. Public Health Service.

Portions of this paper were presented at the 14th Danavox Symposium, Faaborg, Denmark, September 25–28, 1990.

REFERENCES


