# Everyday Speech Understanding by Older Listeners

Karen S. Helfer
*University of Massachusetts*

The differences between audiologic testing and everyday communication may be overlooked when determining which older adults should receive rehabilitative services. This is especially true for older listeners with little or no hearing loss. Although some of these individuals have little difficulty in everyday listening conditions, a proportion of them do experience problems with day-to-day communication. Such individuals, however, are rarely advised to seek any kind of intervention. This paper will outline various attributes of everyday communication that may influence an older listener's comprehension of speech messages.

## Introduction

The testing performed during a routine audiologic evaluation yields valuable diagnostic information about the auditory system. Audiologic data are also used as a basis for deciding whether intervention (e.g., hearing aids or aural rehabilitation) is indicated. Routine audiologic tests, however, are poor predictors of the amount of perceived hearing difficulty (Weinstein & Ventry, 1983a, 1983b). A portion of this lack of agreement between measured and self-reported hearing disorder lies in the nature of the environment and stimuli used in audiologic assessment. Clients are seated in sound-treated rooms where they listen to pure tones and monosyllabic words presented to each ear separately. The acoustics of an audiometric suite do not simulate most rooms where communication occurs, and the ability to detect pure tones and repeat back isolated monosyllabic words is rarely important in day-to-day communication. In the majority of listening situations, individuals also have the opportunity to use visual cues to enhance perception. Hence, a typical hearing assessment leaves us with an incomplete or inaccurate picture of how our clients are performing outside of the clinic.

Older adults comprise a large proportion of many audiologists' caseloads. The discrepancy between measured and actual communication performance may be especially marked for this population. Physiologic changes not tapped in basic audiologic tests, such as decline in visual processing or cognitive abilities, may

Karen S. Helfer, PhD, is an Assistant Professor of Audiology, Department of Communication Disorders, University of Massachusetts, Arnold House, Amherst, MA, 01003.

lead to significant communication problems in elderly individuals who have only a mild degree of peripheral hearing loss. Indeed, evidence exists to support the contention that older adults with minimal pure-tone hearing loss often experience difficulty understanding speech distorted by room acoustics (Bergman, 1980; Harris & Reitz, 1985; Helfer & Wilber, 1990; Nabelek, 1988; Nabelek & Robinson, 1982). Because they perform well on routine audiologic tests and their hearing loss is not significant enough to justify recommending a hearing aid, these individuals are typically not advised to seek intervention.

This paper will discuss experimental evidence relevant to real-life listening. Various parameters of communication not typically examined during audiologic evaluation will be discussed as they apply to older adults. The focus will be on older listeners with minimal hearing loss because it is for these individuals that the judgement about whether to recommend rehabilitation may be particularly difficult. Several methods for improving our decisions regarding rehabilitation will be offered.

## Listening in the "Real World"

### A. Room Acoustics

Although the acoustics in listening environments vary greatly, most rooms are noisy and reverberant to some degree. The type and level of noise influences how detrimental it will be to communication (e.g., Pearsons, Bennett, & Fidell, 1977). This poses a problem for tests designed to simulate realistic listening – how do we select a noise type and level that is representative of actual communication environments? It would be impossible to sample each listening environment a person is likely to encounter; however, limited evidence suggests that older individuals who have difficulty with one type of competition may also be affected by a different source of noise (Bergman, 1980).

Because younger adults with hearing impairment have difficulty understanding speech in noise (e.g., Zurek & Delhorne, 1987) it is not surprising that most older, hearing-impaired subjects also demonstrate problems on such tasks (Jokinen, 1973; Plomp & Mimpen, 1979). When older and younger subjects are matched audiometrically, the older group typically obtains poorer scores on tasks of speech perception in noise (Findlay & Denenberg, 1977; Townsend & Bess, 1980).

Older adults with minimal amounts of hearing loss also may experience difficulty processing speech in noise. This problem can be demonstrated on syllable-level stimuli – elderly individuals with little or no hearing loss produce more errors than young, normal hearing listeners on nonsense syllable tasks, but the types of errors are similar (Gelfand, Piper, & Silman, 1986; Gordon-Salant, 1987b; Helfer & Huntley, 1991; Smith & Prather, 1971). As compared to younger listeners, older minimally hearing-impaired adults need a more advantageous signal-to-noise ratio to reach a given level of performance (Dubno, Dirks, & Morgan, 1984; Gelfand, Ross, & Miller, 1988; Gordon-Salant, 1987a).

The perception of reverberant speech is problematic for many older individuals (Harris & Reitz, 1985; Helfer & Wilber, 1990; Humes & Roberts, 1990; Nabelek, 1988; Nabelek & Robinson, 1982) even if their hearing loss is not sufficient to consider them candidates for hearing aids (Helfer & Wilber, 1990; Nabelek & Robinson, 1982). Figure 1 displays results of several studies addressing speech perception in reverberation by older adults. It is apparent that older listeners have some difficulty understanding reverberated speech, especially if they are hearing-impaired. It should also be noted that many of the older, minimally hearing-impaired subjects in these studies obtained scores in quiet similar to those of young normal-hearing listeners. Thus, the speech perception measures in quiet that are obtained during routine audiologic evaluation might be misleading if generalized to real-life listening. Individual variability in susceptibility to reverberation is often marked, making the prediction of who will have difficulty in day-to-day communication even more problematic (Bergman, 1980; Helfer & Wilber, 1990; Nabelek, 1988; Nabelek & Letowski, 1985; Nabelek & Pickett, 1974).

Noise and reverberation co-exist in most rooms. Older hearing-impaired listeners need a more advantageous signal-to-noise ratio in reverberant environ-

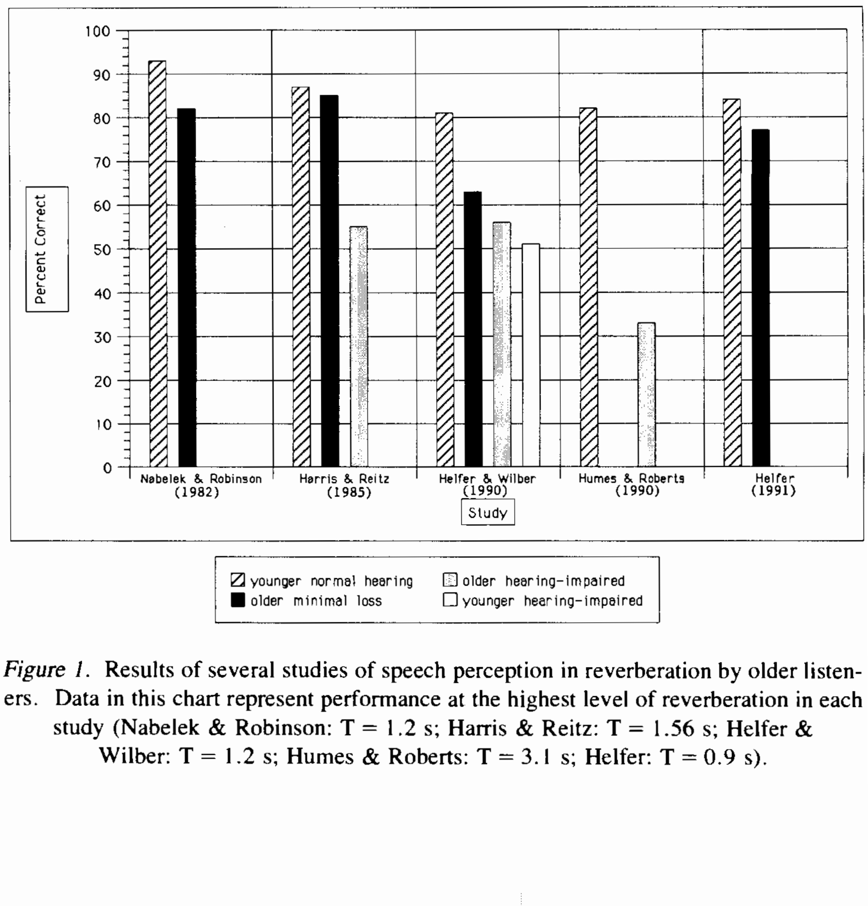


*Figure 1.* Results of several studies of speech perception in reverberation by older listeners. Data in this chart represent performance at the highest level of reverberation in each study (Nabelek & Robinson: T = 1.2 s; Harris & Reitz: T = 1.56 s; Helfer & Wilber: T = 1.2 s; Humes & Roberts: T = 3.1 s; Helfer: T = 0.9 s).

**Table 1**

Summary of Studies of the Perception of Rate-Altered Speech by Older Listeners

| Study | Material | Alteration in Rate | Subjects | Results |
|---|---|---|---|---|
| Calearo & Lazzaroni (1957) | sentences | 140 wpm (normal), 250 wpm, 350 wpm (natural) | 70-85 years; age-normal hearing | – age-related difficulty with speeded speech<br>– increase in level did not overcome rate-related difficulty |
| Luterman, Welsh & Melrose (1966) | W-22 words | 10% and 20% expansion and compression (electronic) | 79-87 years; high-frequency hearing loss | – compression caused decline in scores; expansion had little effect |
| Sticht & Gray (1969) | W-22 words | 36%, 46%, 59% compression (electronic) | over 60 years; hearing-impaired and normal hearing | – age-related decline in identification<br>– older subjects with normal hearing scored poorer than young hearing-impaired subjects in the most distorted condition |
| Schon (1970) | W-22 words | 30% and 50% expansion and compression (electronic) | 65-85 years; age-normal hearing or minimal hearing loss | – both older groups' scores were poorer than those obtained by younger subjects with similar thresholds<br>– expansion caused decline in scores, especially for hearing-impaired subjects |
| Konkle, Beasley, & Bess (1977) | NU-6 words | 20%, 40%, 60% compression (electronic) | 54-84 years; age-normal hearing | – amount of decline from compression increased with age |
| Korabic, Freeman, & Church (1978) | NU-6 words | 30%, 60%, 100% expansion (electronic) | 65-73 years; age-normal hearing | – expansion caused decline in scores relative to unexpanded condition; perception poorest at 60% expansion |

*Continued on next page*

**Table 1** *Continued*

| Study | Material | Alteration in Rate | Subjects | Results |
|---|---|---|---|---|
| Schmitt & McCroskey (1981) | sentences (picture identification) | 60% compression, 140% and 180% expansion (electronic) | 65-88 years; age-normal hearing | – scores at 140% expansion and 60% compression significantly better than at other rates |
| Schmitt (1983) | passages/ questions | 60% compression, 140% and 180% expansion (electronic) | 65-74 years or 75-84 years; age-normal hearing | – young-olds performed significantly better than old-olds at all rates<br>– expansion (especially greater amount) aided comprehension in young-old group but interfered with perception by old-old subjects |
| Wingfield, Poon, Lombardi, & Lowe (1985) | sentences or word strings | 275, 325, 375, 425 wpm (electronic) | 65-73 years; thresholds not reported | – effect of rate larger for older subjects<br>– syntactic information helped older subjects overcome rate effect |
| Schmitt & Carroll (1985) | passages/ questions | 60% compression, 140% and 180% expansion (natural) | 65-74 years; age-normal hearing | – 60% compression yielded poorest performance; no significant effect of expansion |
| Stine, Wingfield, & Poon (1986) | sentences | 200, 300, 400 wpm (electronic) | 61-82 years; two levels of education and verbal ability | – age differences increased with increasing rate<br>– older subjects with lower education/verbal level performed more poorly than other elderly participants (but had same amount of decline) |
| Wingfield & Stine (1986) | passages (recall) | 200 and 350 wpm (electronic) | 65-80 years; subjects reported good hearing | – older subjects recalled less words at fast rate than did younger subjects (no age differences at slower rate) |
| Schmitt & Moore (1989) | passages/ questions | 60% compression, 140% and 180% expansion (natural) | 75-84 years; age-normal hearing | – 60% compression caused significantly poorer performance; expansion had little effect<br>– no significant difference in performance between these old-old subjects and the young-old subjects from Schmitt & Carroll (1985) |

ments (Duquesnoy & Plomp, 1980; Plomp & Duquesnoy, 1980). All listeners experience some reduction in perception when reverberation and noise are combined, but the deficit is compounded for individuals who are older and/or hearing-impaired. Unfortunately, performance in noisy, reverberant rooms may not be predictable from scores obtained in noise alone (Finitzo-Hieber & Tillman, 1978; Nabelek & Mason, 1981).

### B. Speech Rate

Some older adults ascribe their speech perception problems to younger talkers who speak too rapidly. A general slowing of processing speed is a hallmark of the aging process (e.g., Birren, Woods, & Williams, 1980). Experimental evidence concurs with older listeners' subjective comments – elderly individuals experience difficulty understanding rapid speech. Studies of the perception of rate-altered speech by older adults are summarized in Table 1.

Data in Table 1 suggest that the decoding of rapid speech is troublesome for older listeners. This difficulty can be demonstrated using either electronic compression or natural (speaker-generated) rate change on a wide variety of tasks. The relative contribution of hearing loss vs. aging *per se* on the perception of time-altered speech is not clear from existing studies. Hearing loss above 3kHz is detrimental to the understanding of compressed speech (Harris, 1960). The results of several studies suggest that the amount of perceptual decline from compression is the same in groups of older and younger subjects matched for amount of hearing loss (Luterman, Welsh, & Melrose, 1966; Otto & McCandless, 1982; Schon, 1970). However, there is limited evidence suggesting that older adults with minimal hearing loss also are at a disadvantage when they must understand compressed monosyllables (Sticht & Gray, 1969).

An unexpected finding in several studies is that expansion of speech does not improve perception by older adults. This is in contrast to what many audiologists observe daily – speaking slowly to an older person is often an effective strategy. One possible explanation is that the electronic expansion used in most studies causes a distortion of the signal that offsets any benefit from slowing the rate. Two studies exploring comprehension of naturally-expanded passages (Schmitt & Carroll, 1985; Schmitt & Moore, 1989), however, show that little improvement in understanding is obtained by older listeners with "age-normal" hearing when the speaking rate is slowed.

### C. Message Differences

Monosyllabic word tests are adequate for audiologic evaluation because they are standardized and take relatively little time to administer. The understanding of conversational speech, however, requires more than just the reception of speech sounds. Because words used in conversations are typically related to a common topic, higher-level cognitive skills are important in many communicative interactions. Some of these abilities have been demonstrated to be susceptible to the aging process. Auditory sequencing and auditory memory appear to decline in older adults (Neils, Newman, Hill, & Weiler, 1991; Trainor & Trehub, 1989). Hearing loss itself may tax auditory memory – individuals who must expend processing energy to identify words may have fewer resources available to allocate to memory strategies such as categorization, mnemonics, and rehearsal (Rabbitt, 1991). Indeed, deficits in higher level processing have been demonstrated when older adults must decode complex sentences (Bergman, 1980; Emery, 1986; Feier & Gerstman, 1980; Lesser, 1976).

On the other hand, adults of all ages are adept at using certain aspects of language to aid speech understanding in adverse listening conditions. For example, elderly subjects do tend to take advantage of lexical context – they can recognize phonemes in words more easily than in nonsense syllables (Nittrouer & Boothroyd, 1990). Older adults can also use contextual information (Kalikow, Stevens, & Elliott, 1977; Nittrouer & Boothroyd, 1990) and grammatical redundancy (Fullerton & Smith, 1980) to aid speech understanding. Moreover, older listeners can use syntactic constraints to help overcome problems associated with increased rate (Wingfield, Poon, Lombardi, & Lowe, 1985) although increasing the presentation level does not alleviate rate-produced misperceptions (Celearo & Lazzaroni, 1957). Because the repetition of monosyllabic words requires little higher-level processing, routine speech discrimination testing does not take into account potential listener differences in the use of these strategies.

### D. Speaker Differences

Some sources of differences in intelligibility among speakers' voices are obvious (e.g., gender and dialect). A large amount of variability in the clarity of speech also exists among speakers of the same dialect and gender. Differences in speakers' voices may further interact with the listening environment (Cox, Alexander, & Gilmore, 1987). Data also exist suggesting that a speaker who is easy to understand in the auditory domain may not necessarily be easy to speechread (e.g., Kricos & Lesner, 1982).

Most material generated for assessing speech perception is recorded in what would be considered a clear, deliberate manner. Research has demonstrated that there are measurable differences between clear and conversational speech. When speakers are asked to talk clearly, acoustic changes occur that translate into improvement in intelligibility for hearing-impaired listeners (Picheny, Durlach, & Braida, 1985). A large portion of the difference between clear and conversational speech is rate, with clear speech being slower from the insertion of pauses between words and the extension of the duration of phonemes (Picheny et al., 1985, 1986). This enhancement in intelligibility cannot be explained entirely by rate (Picheny et al., 1989) – conversational speech is also characterized by vowel reductions, stop-burst deletion, and reduced consonant-vowel ratio. Moreover, rate cannot predict the intelligibility of voices in various listening environments (Cox et al., 1987). It should be noted that none of these studies examined listener age as a variable in the understanding of clear versus conversational speech. In light of the research findings that naturally expanded speech does not lead to improved comprehension by older listeners, one should use caution when generalizing these data to elderly individuals.

Another source of variation in speech has to do with speaker age. Older people are more likely to have older communication partners (Shadden, 1988). Age-related differences have been documented in older speakers' voices, including decreased frequency range (Ptacek, Sander, Maloney, & Jackson, 1966), shorter voice-onset time (Neiman, Klich, & Shuey, 1983) and, for males, imprecise articulation (Hartman & Danhauer, 1976).

What implications do these vocal changes have for communication among older adults? We have begun a series of studies addressing the interaction of the aging voice with the aging auditory system. For our first study (Huntley & Helfer, 1990) voice samples were obtained from 20 older healthy adults (10 males, 10 females). These talkers were between 59 and 86 years of age (mean 68.55 years). The samples were obtained in two ways – the subjects were first asked simply to read two kinds of material (the Rainbow Passage and lists from the SPIN test [Kalikow et al., 1977]). These initial readings will be called the "normal" recordings. The subjects were then asked to read the material as if they were speaking to a person of approximately their own age (these will be referred to as the "peer" productions).

The first analysis of data focused on age-related differences in the subjects' voices. We generated a recording consisting of samples of each subject's voice (using the "normal" production). This tape was played to 12 college-aged students who were asked to estimate each speaker's age. These perceived age scores were used in a Pearson r correlation matrix along with chronologic age and a number of acoustic variables measured from the voice samples (rate, fundamental frequency, F1/F2 ratio, quality, and intensity). Chronologic and perceived age were both correlated negatively with rate (chronologic age: $r = -.70$, $p < .001$; perceived age, $r = -.46$, $p < .01$). Correlations between the age indices and other acoustic variables were nonsignificant. These results concur with a number of earlier explorations of the aging voice (e.g., Ptacek et al., 1966) showing that both chronologic and perceived age are associated with a slow vocal rate.

The next analysis of these data (Huntley & Helfer, 1991) examined acoustic differences between the "peer" and "normal" productions. It was hypothesized that older adults might slow their vocal rate to an even greater extent when addressing peers because of either an age stereotype or from experience (that is, previous conversations with older listeners who have difficulty processing rapid speech). Indeed, the largest apparent difference between the "peer" and "normal" productions was rate. Contrary to what was expected, Analysis of Variance demonstrated that the "peer" productions (mean rate = 4.90 syllables/second) were significantly faster than the "normal" productions (mean rate = 4.44 syllables/second) for both male and female speakers ($F(1, 18) = 2.11$, $p < .001$). Males spoke significantly slower than females (mean rate = 4.4 syllables/second for males, 4.9 syllables/second for females; $F(1, 18) = 4.19$, $p = .007$) but the interaction between gender and peer/normal rate differences was nonsignificant. It is not known whether the subjects increased their speaking rate on the "peer" productions because it was their second reading of similar material or because they were given specific instructions on how to read. It is also possible that older adults actually do speak more quickly to age peers. Subsequent studies will not only attempt to clarify this issue, but will also examine differences in the perception of the "normal" versus "peer" sentences by older listeners.

### E. Visual Information

Face-to-face communication allows individuals to use both auditory and visual speech information. Deficits in visual processing have been noted in older adults. For example, visual short-term memory appears to be more susceptible to aging than is auditory short-term memory (Boyle, Aparicio, Kaye, & Acker, 1975). Other cognitive abilities that may influence speechreading are prone to the negative effects of aging. For instance, vigilance (as measured using a clock-watching task) declines with age (Quilter, Giambra, & Benson, 1983) and older adults have difficulty ignoring visually-presented irrelevant stimuli (Hoyer, Rebok, & Sved, 1979; Scialfa, Kline, & Lyman, 1987).

Speechreading ability is noted to decline with increasing age (Arlinger, 1991; Ewertsen & Birk-Nielsen, 1971; Farrimond, 1959; Pelson & Prather, 1974; Shoop & Binnie, 1979). Older adults, however, can improve speechreading perception by using visual cues such as descriptive pictures (Farrimond, 1959) and can also combine auditory and visual information (Danhauer, Garnett, & Edgerton, 1985; Ewertsen & Birk-Nielsen, 1971; Garstecki, 1983).

Speechreading is not measured routinely during audiologic assessment. Perhaps some of the variability in the degree to which older adults experience problems communicating in real rooms is related to speechreading ability.

### F. Binaural Hearing

The benefit of listening with two ears in less-than-ideal conditions has been well documented. Studies of binaural processing by older listeners have demonstrated age-related deficits in such binaural phenomena as the masking-level difference (Findlay & Schuchman, 1976; Novak & Anderson, 1982; Olsen, Noffsinger, & Carhart, 1976; Pichora-Fuller & Schneider, 1990; Tillman, Carhart, & Nicholls, 1973; Warren, Wagener, & Herman, 1978), interaural time discrimination (Herman, Warren, & Wagener, 1977; Kirikae, 1969; Matzker & Springhood, 1958), and the precedence effect (Cranford, Boose, & Moore, 1990). Studies of binaural speech perception suggest that older adults do benefit from using binaural cues, but to a lesser degree than younger listeners (Duquesnoy, 1983; Nabelek & Robinson, 1982; Tillman, Carhart, & Nicholls, 1970).

Evidence exists, however, suggesting that the peripheral hearing loss accompanying presbycusis is the limiting factor in binaural processing. Young hearing-impaired listeners often show abnormally poor binaural abilities (Durlach, Thompson, & Colburn, 1981). A number of studies have revealed little age-related change on binaural fusion (Harbert, Young, & Menduke, 1966; Palva & Jokinen, 1970) and on a variety of binaural tasks when younger and older subjects are matched on amount of hearing loss (Kelly-Ballweber & Dobie, 1984). Further, the size of the binaural advantage appears to be more closely related to amount of hearing loss in older subjects than to chronologic age. Gelfand, Ross, and Miller (1988) explored the threshold for sentences in noise originating at the same spatial location as the speech or from a loudspeaker situated 90° relative to the primary signal. Three groups of normal-hearing subjects (young, middle-aged, and elderly) and a group of listeners with presbycusis were included in the study. Although overall performance was poorer in the two groups of elderly listeners (as compared to the young, normal-hearing group), the amount of binaural advantage from spatial separation of the speech and noise was significantly smaller only for the participants with presbycusis.

The influence of aging on the binaural advantage in reverberation and noise was addressed by comparing monaural and binaural consonant perception in younger and older listeners (Helfer, 1991). The subjects in this study were nine young, normal-hearing adults and nine older adults (60-73 years, mean 65.7 years) with little or no hearing loss (a mean pure-tone average of 10.3 dB HL and a mean high-frequency pure-tone average (2k, 3k, 4k, 6kHz) of 24.2 dB HL). All subjects were native English speakers who reported a negative history of otologic and neurologic disorder. In addition, all participants had symmetric audiograms.

The CUNY Nonsense Syllable Test was re-recorded to yield four listening conditions: quiet, noise (at a +10 dB signal-to-noise ratio), reverberation ($T = 0.9$ s), and reverberation plus noise. Recordings were generated with the use of a KEMAR mannequin in order to produce test stimuli with possible binaural cues. All participants listened to the stimuli under both monaural and binaural presentation modes delivered through insert earphones at a set presentation level of 82 dB SPL.

Although the older subject group scored significantly poorer than the younger group in the reverberation condition ($F(1, 16) = 10.17$, $p = .006$) group differences in the amount of binaural gain in each listening condition were nonsignificant. This was due, in part, to the large amount of variability noted for the binaural advantage in both subject groups. Further, correlation coefficients were small (and nonsignificant) between age and binaural gain, and between the amount of pure-tone hearing loss and binaural gain. The data from this study suggest that aging itself does not reduce the ability to use binaural information in these older adults with little or no peripheral hearing loss.

### G. Interaction of Distortions

In everyday listening situations a number of distortions are likely to be concurrent. For example, people may speak rapidly in noisy, reverberant rooms to hearing-impaired individuals. Several studies of the interaction of distortions suggest that the effect of multiple degrading factors is additive – levels of distor-

**Table 2**

Amount of Score Decline from Reverberation, Noise, and the Combination of Reverberation and Noise

| Study | Subjects | T → % Decline | dB S/N → % Decline | Predicted R + N % Decline | Actual R + N % Decline |
|---|---|---|---|---|---|
| Moncur & Dirks (1967) | young normals | 2.3 → 38 | 0 → 31 | 68 | 75 |
| Crum (1974) | young normals | 1.2 → 5 | 0 → 51 | 56 | 77 |
| Nabelek & Pickett (1974) | young normals | 0.3 → 3 | −5 → 21 | 24 | 37 |
| | young hearing-impaired | 0.3 → 16 | −5 → 27 | 43 | 33 |
| Nabelek & Mason (1981) | hearing-impaired (wide age range) | 0.5 → 16 | +5 → 17 | 33 | 54 |
| Harris & Reitz (1985) | young normals | 1.56 → 9 | +10 → 5 | 14 | 27 |
| | older, minimal loss | 1.56 → 12 | +10 → 6 | 18 | 43 |
| | older hearing-impaired | 1.56 → 29 | +10 → 9 | 38 | 48 |
| Harris & Swenson (1990) | young normals | 1.56 → 9 | +10 → 4 | 14 | 27 |
| | young, mild hearing loss | 1.56 → 20 | +10 → 11 | 31 | 44 |
| | young, mod./severe loss | 1.56 → 36 | +10 → 12 | 49 | 43 |
| Helfer & Wilber (1990) | young normals | 0.9 → 13 | +10 → 16 | 29 | 40 |
| | young hearing-impaired | 0.9 → 24 | +10 → 21 | 45 | 46 |
| | older minimal loss | 0.9 → 19 | +10 → 23 | 43 | 45 |
| | older hearing-impaired | 0.9 → 18 | +10 → 24 | 42 | 47 |
| Humes & Roberts (1990) | young normals | 3.1 → 15 | +5 → 11 | 25 | 26 |
| | older hearing-impaired | 3.1 → 38 | +5 → 23 | 60 | 41 |

*Note.* The columns labelled "T → % Decline" and "dB S/N → % Decline" represent amount of distortion (reverberation time [T] in seconds) and the amount of decline from that degradation relative to performance with no distortion. The Predicted Decline is the amount of score reduction that would be predicted from adding the effects of noise and reverberation. The Actual Decline is the score reduction measured from listeners when noise and reverberation were both present.

tion that cause little difficulty in isolation, when combined, may lead to a large reduction in intelligibility. This is true of the combination of low-pass filtering, amplitude modulation, and multiple echoes (Martin, Murphy, & Meyer, 1956); compression, interruption, masking, and high-frequency hearing loss (LaCroix & Harris, 1979); and reverberation, masking, filtering, and changes in speech level (Loven & Collins, 1988). A multiplicative effect has been demonstrated for the combination of reverberation and noise – when these two distortions are both present, the decrease in perception is often greater than would be predicted from simply adding the amount of degradation obtained separately from each factor. This suggests that noise and reverberation have somewhat different effects on the speech signal. Table 2 summarizes a number of studies of speech perception in reverberation and noise.

A multiplicative model of distortion may also be applied to older listeners. Figure 2 depicts this multiplicative model of speech perception in aging. Older

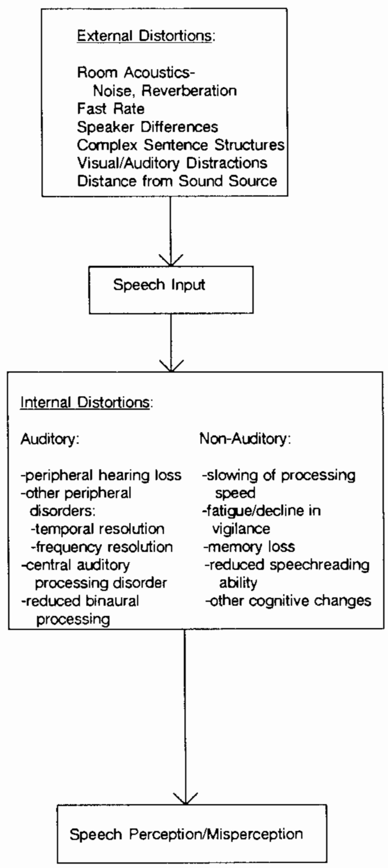


*Figure 2.* Multiplicative model of speech perception in aging.

adults may have a number of internal distortions, such as loss of hearing sensitivity, other peripheral auditory changes (i.e., reduced frequency resolution or temporal acuity), central auditory deficits, visual system decline, and/or cognitive changes. These internal distortions, even if minor, may interact with external distortions of the speech signal (e.g., reverberation, noise, fast rate). The end result may be reduced intelligibility even in the absence of large amounts of any one internal distortion. This might explain why a proportion of older individuals with little or no peripheral hearing loss who have little difficulty understanding speech in quiet have marked problems with everyday speech perception.

**Implications for Hearing Assessment and Intervention**

The information gained from audiologic assessment may not adequately predict the need for intervention. It can probably be assumed that most older adults with a significant amount of hearing loss have difficulty in typical listening environments. The prediction of the performance of older adults with little or no hearing loss is more complicated. Some older, minimally hearing-impaired listeners experience speech perception difficulty in noise (Dubno, Dirks, & Morgan, 1984; Gelfand, Ross, & Miller, 1988; Gordon-Salant, 1987) and in reverberation (Bergman, 1980; Harris & Reitz, 1985; Helfer, 1991; Helfer & Wilber, 1990; Nabelek, 1988; Nabelek & Robinson, 1982).

At least two problems exist when attempting to apply these data to real-life listening. This first difficulty lies in the variability noted in the majority of studies using older adults with minimal hearing loss. While some of these individuals demonstrate significant problems with speech understanding, others achieve performance similar to that of young, normal-hearing subjects. This variability can be observed clinically in the wide range of problems reported by older clients with "borderline-normal" hearing sensitivity. Attempts should be made to identify contributing factors to this variability. If the sources of difficulty can be identified, audiologists may be better able to predict which individuals might benefit from intervention.

The second problem is that the face validity of many experimental tasks is questionable; for example, the perception of nonsense syllables which has been distorted by reverberation and noise is not related to amount of self-perceived hearing handicap. Correlation coefficients between scores on the Self-Assessment of Communication (Schow & Nerbonne, 1982) and percent-correct performance on the binaural advantage study discussed earlier (Helfer, 1991) ranged between −.07 and −.22. Similar results have been shown when attempting to correlate hearing handicap measures with the perception of monosyllabic words (Weinstein & Ventry, 1983a, 1983b) or with sentence perception in either quiet or noise (Gatehouse, 1991; Lutman, 1991).

The development of test measures which better simulate actual communication (and thus are more predictive of how clients perform in the real world) would represent a great improvement in the clinical assessment of speech perception. One sizeable dilemma faced by anyone attempting to develop such measures would be in deciding how to choose the communication environment(s) and task(s) to be simulated. An appropriate first approximation might be to include both reverberation and noise in routine clinical assessment of speech understanding.

Hearing handicap scales remain a strong indication of the functional ability of listeners in everyday communication situations. Because of the inadequacies of present test measures in predicting real-life performance, the data from hearing handicap scales should be taken into account when decisions are made regarding intervention. This is especially true when the client is an older individual who demonstrates "sub-clinical" hearing changes on audiometric measures.

If older, minimally hearing-impaired adults will be advised to seek hearing rehabilitation, programs should be designed to address their needs. Because these individuals will have little difficulty in face-to-face conversation, intervention needs to incorporate realistic, challenging tasks (e.g., different speakers, various sources of distortion). One useful model is the meta-communication approach developed by Erber (1988). This type of intervention program has the potential to help older individuals identify and resolve communication problems outside of the clinic.

In addition to communication-related tasks, "pre-crisis" intervention may be incorporated into rehabilitation programs. Clients could be educated about hearing aids and hearing loss prior to needing amplification. Perhaps these individuals can then act as peer counselors to other elders to help foster acceptance and dispel inaccurate information about hearing loss and hearing aids. Audiologists may need to be more flexible regarding both candidacy for and the nature of activities that fall within the realm of aural rehabilitation.

## REFERENCES

Arlinger, S. (1991). Audiometric profile in presbycusis. *Acta Otolaryngologia* (Suppl. 476), 85-90.

Bergman, M. (1980). *Aging and the perception of speech.* Baltimore: University Park Press.

Birren, J.E., Woods, A.M., & Williams, M.V. (1980). Behavioral slowing with age: Causes, organization, and consequences. In L.W. Poon (Ed.), *Aging in the 1980s.* Washington, DC: APA.

Boyle, E., Aparicio, A.M., Kaye, J., & Acker, M. (1975). Auditory and visual memory losses in aging populations. *Journal of the American Geriatric Society, 23,* 284-286.

Calearo, C., & Lazzaroni, A. (1957). Speech intelligibility in relation to the speed of the message. *Laryngoscope, 67,* 410-419.

Cox, R.M., Alexander, G.C., & Gilmore, C. (1987). Intelligibility of average talkers in typical listening environments. *Journal of the Acoustical Society of America, 81,* 1598-1608.

Cranford, J.L., Boose, M., & Moore, C.A. (1990). Effects of aging on the precedence effect in sound localization. *Journal of Speech and Hearing Research, 33,* 654-659.

Crum, M. (1974). *Effects of reverberation, noise and distance upon speech intelligibility in small, classroom size acoustic enclosures.* Unpublished doctoral dissertation, Northwestern University, Evanston, IL.

Danhauer, J.L., Garnett, C.M., & Edgerton, B.J. (1985). Older persons' performance on auditory, visual, and auditory-visual presentations of the Edgerton and Danhauer Nonsense Syllable Test. *Ear and Hearing, 6,* 191-197.

Dubno, J.R., Dirks, D.D., & Morgan, D.E. (1984). Effects of age and mild hearing loss on speech recognition in noise. *Journal of the Acoustical Society of America, 76,* 87-96.

Duquesnoy, A.J. (1983). Effect of a single interfering noise or speech source upon the binaural sentence intelligibility of aged persons. *Journal of the Acoustical Society of America, 74,* 739-743.

Duquesnoy, A.J., & Plomp, R. (1980). Effect of reverberation and noise on the intelligibility of sentences in cases of presbyacusis. *Journal of the Acoustical Society of America, 68,* 537-544.

Durlach, N.I., Thompson, C.L., & Colburn, H.S. (1981). Binaural interaction in impaired listeners. *Audiology, 20,* 181-211.

Emery, O.B. (1986). Linguistic decrement in normal aging. *Language and Communication, 6,* 47-64.

Erber, N.P. (1988). *Communication therapy for hearing-impaired adults.* Washington, DC: A.G. Bell.

Ewertsen, H.W., & Birk-Nielson, H.B. (1971). A comparative analysis of the audiovisual, auditive and visual perception of speech. *Acta Otolaryngologica, 72,* 201-205.

Farrimond, T. (1959). Age differences in the ability to use visual cues in auditory communication. *Language and Speech, 2,* 179-192.

Feier, C.D., & Gerstman, L.J. (1980). Sentence comprehension abilities throughout the adult life-span. *Journal of Gerontology, 35,* 722-728.

Findlay, R.C., & Denenberg, L.J. (1977). Effect of subtle mid-frequency auditory dysfunction upon speech discrimination in noise. *Audiology, 16,* 252-259.

Findlay, R.C., & Schuchman, G.I. (1976). Masking level difference for speech: Effects of ear dominance and age. *Audiology, 15,* 232-241.

Finitzo-Hieber, T., & Tillman, T.W. (1978). Rooms acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. *Journal of Speech and Hearing Research, 21,* 440-458.

Fullerton, A.M., & Smith, A.D. (1980). Age-related differences in the use of redundancy. *Journal of Gerontology, 35,* 729-735.

Garstecki, D.C. (1983). Auditory, visual and combined auditory-visual speech perception. *Journal of the Academy of Rehabilitative Audiology, 16,* 221-233.

Gatehouse, S. (1991). The role of non-auditory factors in measured and self-reported disability. *Acta Otolaryngologica* (Suppl. 476), 249-256.

Gelfand, S.A., Piper, N., & Silman, S. (1986). Consonant recognition in quiet and in noise with aging among normal hearing listeners. *Journal of the Acoustical Society of America, 80,* 1589-1598.

Gelfand, S.A., Ross, L., & Miller, S. (1988). Sentence reception in noise from one versus two sources: Effects of aging and hearing loss. *Journal of the Acoustical Society of America, 83,* 248-256.

Gordon-Salant, S. (1987a). Age-related differences in speech recognition performance as a function of test format and paradigm. *Ear and Hearing, 8,* 277-282.

Gordon-Salant, S. (1987b). Consonant recognition and confusion patterns among elderly hearing-impaired subjects. *Ear and Hearing, 8,* 270-276.

Harbert, F., Young, I.M., & Menduke, H. (1966). Audiological findings in presbycusis. *Journal of Auditory Research, 6,* 297-312.

Harris, J.D. (1960). Combinations of distortion in speech. *Archives of Otolaryngology, 72,* 227-232.

Harris, R.W., & Reitz, M.L. (1985). Effects of room reverberation and noise on speech discrimination in the elderly. *Audiology, 24,* 319-324.

Harris, R.W., & Swenson, D.W. (1990). Effects of reverberation and noise on speech recognition by adults with various amounts of sensorineural hearing loss. *Audiology, 29,* 314-321.

Hartman, D.E., & Danhauer, J.L. (1976). Perceptual features of speech for males in four perceived age decades. *Journal of the Acoustical Society of America, 59,* 713-715.

Helfer, K.S. (1991). Aging and the binaural advantage in reverberation and noise. Manuscript in progress.

Helfer, K.S., & Huntley, R.A. (1991). Aging and consonant errors in reverberation and noise. *Journal of the Acoustical Society of America, 90,* 1786-1796.

Helfer, K.S., & Wilber, L.A. (1990). Hearing loss, age and speech perception in reverberation and noise. *Journal of Speech and Hearing Research, 33,* 149-155.

Herman, G.E., Warren, L.R., & Wagener, J.W. (1977). Auditory lateralization: Age differences in sensitivity to dichotic time and amplitude cues. *Journal of Gerontology, 32,* 187-191.

Hoyer, W.J., Rebok, G.W., & Sved, S.M. (1979). Effects of varying irrelevant information on adult age differences in problem solving. *Journal of Gerontology, 34,* 553-560.

Humes, L.E., & Roberts, L. (1990). Speech-recognition difficulties of the hearing-impaired elderly: The contributions of audibility. *Journal of Speech and Hearing Research, 33,* 726-735.

Huntley, R.A., & Helfer, K.S. (1990, November). *Effects of presbycusis on voice production.* Presented at the American Speech-Language-Hearing Association annual convention, Seattle, WA.

Huntley, R.A., & Helfer, K.S. (1991, November). *Prosodic aspects of speech among elders.* Presented at the American Speech-Language-Hearing Association annual convention, Atlanta, GA.

Jokinen, K. (1973). Presbycusis VI. Masking of speech. *Acta Otolaryngologica, 76,* 426-430.

Kalikow, D.N., Stevens, K.N., & Elliott, L.L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *Journal of the Acoustical Society of America, 61,* 1337-1351.

Kelly-Ballweber, D., & Dobie, R.A. (1984). Binaural interaction measured behaviorally and electrophysiologically in young and old adults. *Audiology, 23,* 181-194.

Kirikae, I. (1969). Auditory function in advanced age with reference to histological changes in the central auditory system. *International Audiology, 8,* 221-230.

Konkle, D.F., Beasley, D.S., & Bess, F.M. (1977). Intelligibility of time-altered speech in relation to chronological aging. *Journal of Speech and Hearing Research, 20,* 108-115.

Korabic, E.W., Freeman, B.A., & Church, G.T. (1978). Intelligibility of time-expanded speech with normally hearing and elderly subjects. *Audiology, 17,* 159-164.

Kricos, P.B., & Lesner, S.A. (1982). Differences in visual intelligibility across talkers. *The Volta Review, 84,* 219-225.

LaCroix, P.G., & Harris, J.D. (1979). Effects of high-frequency cue reduction on the comprehension of distorted speech. *Journal of Speech and Hearing Disorders, 22,* 236-246.

Lesser, R. (1976). Verbal and non-verbal memory components in the Token Test. *Neuropsychologia, 14,* 79-85.

Loven, F.C., & Collins, M.J. (1988). Reverberation, masking, filtering, and level effects on speech recognition performance. *Journal of Speech and Hearing Research, 31,* 681-695.

Luterman, D.M., Welsh, O.L., & Melrose, J. (1966). Responses of aged males to time-altered speech stimuli. *Journal of Speech and Hearing Research, 9,* 226-230.

Lutman, M. (1991). Hearing disability in the elderly. *Acta Otolaryngologica* (Suppl. 476), 239-248.

Martin, D.W., Murphy, R.L., & Meyer, A. (1956). Articulation reduction by combined distortions of speech waves. *Journal of the Acoustical Society of America, 28,* 597-601.

Matzker, V.J., & Springhood, E. (1958). Richtung-Shoren und Lebensalter. *Zeitschrift fur Laryngologie, Rhinologie, Otologie und Ihre Grenzgebiete, 37,* 739-745.

Moncur, J.P., & Dirks, D. (1967). Binaural and monaural speech intelligibility in reverberation. *Journal of Speech and Hearing Research, 10,* 186-195.

Nabelek, A.K. (1988). Identification of vowels in quiet, noise, and reverberation: Relationships with age and hearing loss. *Journal of the Acoustical Society of America, 84,* 476-484.

Nabelek, A.K., & Letowski, T.R. (1985). Vowel confusions of hearing-impaired listeners under reverberant and nonreverberant conditions. *Journal of Speech and Hearing Disorders, 50,* 126-131.

Nabelek, A.K., & Mason, D. (1981). Effect of noise and reverberation on binaural and monaural word identification by subjects with various audiograms. *JSHR, 24,* 375-383.

Nabelek, A.K., & Pickett, J.M. (1974). Monaural and binaural speech perception through hearing aids under noise and reverberation with normal and hearing-impaired listeners. *Journal of Speech and Hearing Research, 17*, 724-739.

Nabelek, A.K., & Robinson, P.K. (1982). Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of the Acoustical Society of America, 71*, 1242-1248.

Neils, J., Newman, C.W., Hill, M., & Weiler, E. (1991). The effects of rate, sequencing, and memory on auditory processing in the elderly. *Journal of Gerontology, 46*, P71-75.

Neiman, G.S., Klich, R.J., & Shuey, E.M. (1983). Voice onset time in young and 70-year-old women. *Journal of Speech and Hearing Research, 26*, 118-123.

Nittrouer, S., & Boothroyd, A. (1990). Context effects in phoneme and word recognition by young children and older adults. *Journal of the Acoustical Society of America, 87*, 2705-2715.

Novak, R.E., & Anderson, C.V. (1982). Differentiation of types of presbycusis using the Masking-Level Difference. *Journal of Speech and Hearing Research, 25*, 504-508.

Olsen, W.O., Noffsinger, D., & Carhart, R. (1976). Masking level differences encountered in clinical populations. *Audiology, 15*, 287-301.

Otto, W.C., & McCandless, G.A. (1982). Aging and auditory site of lesion. *Ear and Hearing, 3*, 110-117.

Palva, A., & Jokinen, K. (1970). Presbycusis V. Filtered speech test. *Acta Otolaryngologica, 70*, 232-241.

Pearsons, K.S., Bennett, R.L., & Fidell, S. (1977). Speech levels in various noise environments. EPA 600/1/77-025, Office of Health & Ecological Effects, Washington, DC.

Pelson, R.O., & Prather, W.F. (1974). Effects of visual message-related cues, age and hearing impairment on speech reading performance. *Journal of Speech and Hearing Research, 17*, 518-525.

Picheny, M.A., Durlach, N.I., & Braida, L.D. (1985). Speaking clearly for the hard of hearing I: Intelligibility differences between clear and conversational speech. *Journal of Speech and Hearing Research, 28*, 96-103.

Picheny, M.A., Durlach, N.I., & Braida, L.D. (1986). Speaking clearly for the hard of hearing II: Acoustic characteristics of clear and conversational speech. *Journal of Speech and Hearing Research, 29*, 434-446.

Picheny, M.A., Durlach, N.I., & Braida, L.D. (1989). Speaking clearly for the hard of hearing III: An attempt to determine the contribution of speaking rate to differences in intelligibility between clear and conversational speech. *Journal of Speech and Hearing Research, 32*, 600-603.

Pichora-Fuller, M.K., & Schneider, B.A. (1990, November). *Age-related changes in monaural and binaural hearing.* Presented at the American Speech-Language-Hearing Association annual convention, Seattle, WA.

Plomp, R., & Duquesnoy, A.J. (1980). Room acoustics for the aged. *Journal of the Acoustical Society of America, 68*, 1616-1621.

Plomp, R., & Mimpen, A.M. (1979). Speech-reception threshold for sentences as a function of age and noise level. *Journal of the Acoustical Society of America, 66*, 1333-1342.

Ptacek, P.H., Sander, E.K., Maloney, W.H., & Jackson, C. (1966). Phonatory and related changes with advanced age. *Journal of Speech and Hearing Research, 9*, 353-360.

Quilter, R.E., Giambra, L.M., & Benson, P.E. (1983). Longitudinal age changes in vigilance over an eighteen year interval. *Journal of Gerontology, 38*, 51-54.

Rabbitt, P. (1991). Mild hearing loss can cause apparent memory failures which increase with age and reduce with IQ. *Acta Otolaryngologica* (Suppl. 476), 167-176.

Schmitt, J.F. (1983). The effects of time compression and time expansion on passage comprehension by elderly listeners. *Journal of Speech and Hearing Research, 26*, 373-377.

Schmitt, J.F., & Carroll, M.R. (1985). Older listeners' ability to comprehend speaker-generated rate alteration of passages. *Journal of Speech and Hearing Research, 28*, 309-312.

Schmitt, J.F., & McCroskey, R.L. (1981). Sentence comprehension in elderly listeners: The factor of rate. *Journal of Gerontology, 36*, 441-445.

Schmitt, J.F., & Moore, J.R. (1989). Natural alteration of speaking rate: The effect on passage comprehension by listeners over 75 years of age. *Journal of Speech and Hearing Research, 32,* 445-450.

Schon, T.D. (1970). The effects on speech intelligibility of time compression and expansion on normal-hearing, hard of hearing, and aged males. *Journal of Auditory Research, 10,* 263-268.

Schow, R.L., & Nerbonne, M.A. (1982). Communication screening profile: Use with elderly clients. *Ear and Hearing, 3,* 135-147.

Scialfa, C.T., Kline, D.W., & Lyman, B.J. (1987). Age differences in target identification as a function of retinal location and noise level: Examination of the useful field of view. *Psychology and Aging, 2,* 14-19.

Shadden, B.B. (1988). *Communication Behavior and Aging.* Baltimore: Williams & Wilkins.

Shoop, C., & Binnie, C.A. (1979). The effects of age on the visual perception of speech. *Scandinavian Audiology, 8,* 3-8.

Smith, R.A., & Prather, W.F. (1971). Phoneme discrimination in older persons under varying signal-to-noise conditions. *Journal of Speech and Hearing Research, 14,* 630-638.

Sticht, T.G., & Gray, B.B. (1969). The intelligibility of time compressed words as a function of age and hearing loss. *Journal of Speech and Hearing Research, 12,* 443-448.

Stine, E.A.L., Wingfield, A., & Poon, L.W. (1986). How much – how fast: Rapid processing of spoken language in later adulthood. *Psychology and Aging, 1,* 303-311.

Tillman, T.A., Carhart, R., & Nicholls, S. (1970). Hearing aid efficiency in a competing speech situation. *Journal of Speech and Hearing Disorders, 13,* 789-811.

Tillman, T.W., Carhart, R., & Nicholls, S. (1973). Release from multiple maskers in elderly persons. *Journal of Speech and Hearing Research, 16,* 152-160.

Townsend, T.H., & Bess, F.H. (1980). Effects of age and sensorineural hearing loss on word recognition. *Scandinavian Audiology, 9,* 245-248.

Trainor, L.J., & Trehub, S.E. (1989). Aging and auditory temporal sequencing: Ordering the elements of repeating tones. *Perception and Psychophysics, 45,* 417-426.

Warren, L.R., Wagener, J.W., & Herman, G.E. (1978). Binaural analysis in the aging auditory system. *Journal of Gerontology, 33,* 731-736.

Weinstein, B., & Ventry, I.M. (1983a). The audiological correlates of hearing handicap in the elderly. *Journal of Speech and Hearing Research, 26,* 148-151.

Weinstein, B.E., & Ventry, I.M. (1983b). Audiometric correlates of the Hearing Handicap Inventory for the Elderly. *Journal of Speech and Hearing Disorders, 48,* 379-384.

Wingfield, A., Poon, L.W., Lombardi, L., & Lowe, D. (1985). Speed of processing in normal aging: Effects of speech rate, linguistic structure, and processing time. *Journal of Gerontology, 40,* 579-585.

Wingfield, A., & Stine, E.L. (1986). Organizational strategies in immediate recall of rapid speech by young and elderly adults. *Experimental Aging Research, 12,* 79-83.

Zurek, P.M., & Delhorne, L.A. (1987). Consonant reception in noise by listeners with mild and moderate hearing loss. *Journal of the Acoustical Society of America, 82,* 1548-1559.