A Review of Speech Perception and Aging: Some Implications for Aural Rehabilitation

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A major complaint of elderly listeners is difficulty understanding speech, particularly in adverse listening environments. Moreover, elderly listeners with similar audiometric configurations often demonstrate varying abilities to understand speech in the presence of noise and/or reverberation. To date, however, it is unclear which auditory mechanisms are responsible for these individual speech-recognition deficits. The present discussion will review literature concerning: (a) individual speech-recognition susceptibility to noise in elderly listeners; and (b) auditory and cognitive hypotheses which might explain individual differences in speech-recognition performance. Finally, theoretical and clinical implications for rehabilitation procedures in the elderly will be discussed.

A pervasive characteristic of aging is an inability to understand speech, particularly in background noise or reverberation (e.g., Bergman, 1980; Crandell, 1991; Dubno, Dirks, & Morgan, 1984; Duquesnoy & Plomp, 1980; Gelfand, Piper, & Silman, 1985; Gordon-Salant, 1987; Harris & Reitz, 1985; Jerger, Jerger, Oliver, & Pirozzolo, 1989; Plomp, 1986; Suter, 1985). To date, however, the auditory and/or cognitive mechanisms responsible for reduced recognition ability in elderly listeners remain unclear. A traditional explanation has been that the speech-recognition deficits reported in the elderly are the result of reduced pure-tone sensitivity associated with presbycusis. Several investigations, however, have demonstrated a relatively poor relationship between recognition ability and the degree and configuration of sensorineural hearing loss (SNHL), with many

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elderly listeners experiencing greater difficulty understanding speech than the pure-tone audiogram would suggest (Bergman, 1980; Crandell, 1991; Duquesnoy & Plomp, 1980; Gaeth, 1948; Plomp, 1986). Stated otherwise, elderly listeners with similar audiometric configurations may exhibit significantly different abilities to understand speech, particularly within degraded listening environments. Individual susceptibility to noise and reverberation may be one reason that elderly listeners receive varying degrees of benefit from rehabilitation strategies. For instance, individuals who are highly susceptible to noise may derive limited benefit from conventional amplification strategies which simply restore audibility to the frequency regions where hearing loss is present (Duquesnoy & Plomp, 1980; Haggard, Trinder, Foster, & Lindblad, 1987; Neuman, Levitt, Mills, & Schwander, 1987; Plomp, 1978, 1986; Stach, Jerger, & Fleming, 1985).

In addition to reduced communicative efficiency, diminished speech-recognition ability may also compromise psychosocial behavior in elderly individuals. For example, geriatric listeners with speech-recognition deficits may experience increased feelings of isolation. Due to the decreased ability to communicate, elderly individuals may isolate themselves from family, friends, and/or social activities. Primarily due to this increased degree of isolation, a higher incidence of depression, loneliness, frustration, and disappointment has been reported in the elderly population (Alpiner, 1979). Indeed, if reduced speech recognition can contribute to the onset of a psychosocial handicap, the audiologist and/or deaf educator should have sufficient knowledge of how elderly listeners process various parameters of auditory information in difficult listening environments in order to facilitate the development of appropriate rehabilitative programs for such listeners. This knowledge will become of paramount importance during the next decade as case loads of elderly patients increase for the health-care professional. Recent estimates project that by the year 2000, the number of individuals 65 years of age or older will exceed 37 million (Payne-Johnson, 1988).

With these considerations in mind, the purpose of the following discussion is threefold. First, this article will examine differences in speech-recognition susceptibility to noise in elderly individuals. Second, several hypotheses to explain individual differences in speech-recognition performance will be examined. Specifically, four hypotheses will be addressed: (a) cochlear processing, (b) central auditory dysfunction, (c) cognitive processing, and (d) models of audibility. Finally, various rehabilitative procedures will be suggested for improving speech-recognition ability in the geriatric patient.

INDIVIDUAL DIFFERENCES IN SPEECH RECOGNITION IN ELDERLY LISTENERS

Prior research has demonstrated that both young and elderly listeners with similar degrees of SNHL, and/or equivalent speech-recognition ability in quiet, may exhibit varying abilities to understand speech in adverse listening environments (Bergman, 1980; Crandell, 1991; Duquesnoy & Plomp, 1980; Gaeth, 1948; Gordon-Salant, 1987; Nabelek & Mason, 1981; Plomp, 1986; Preminger & Wiley, 1985; Walden, Schwartz, Montgomery, & Prosek, 1981; Yoshioka & Thornton, 1980). In a series of investigations that examined speech-recognition susceptibility to noise in elderly listeners, Plomp and colleagues (Duquesnoy & Plomp, 1983; Festen & Plomp, 1983; Plomp, 1986) utilized an adaptive procedure to obtain the Speech Reception Threshold (SRT), or 50% correct performance level, in quiet and in noise for 133 presbycusic listeners with various degrees and configurations of SNHL. Speech stimuli consisted of a series of Dutch sentences presented in speech spectrum noise at 75 dB SPL. Results from these investigations are presented in Figure 1. In this figure, the abscissa indicates the SRT in quiet, while the ordinate shows the signal-to-noise ratio (SNR) required to attain the SRT in noise. Overall, while this figure demonstrates a

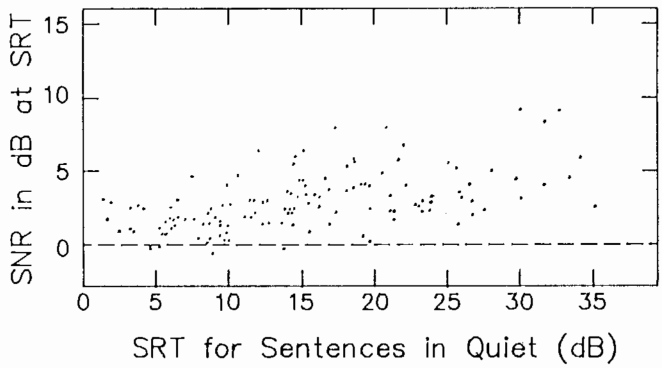

Figure 1. Signal-to-noise ratio (SNR) required for Speech Reception Threshold (SRT) as a function of SRT in quiet for 133 hearing-impaired listeners. (From "A signal-to-noise ratio model for the speech-reception threshold of the hearing impaired" by R. Plomp, 1986, *Journal of Speech and Hearing Research, 29*, pp. 146-154. Adapted by permission.)

moderate relationship ($r = 0.55$; 30% of the total variance explained) between speech-recognition ability in quiet and in noise, note that individuals with identical SRTs in quiet typically demonstrate a substantial range (approximately 10 dB) for SRTs in noise. While these performance differences may initially appear inconsequential, relatively small changes in SNR can equate to large differences in percentage-correct scores (Duquesnoy, 1983; Duquesnoy & Plomp, 1980, 1983; Plomp, 1978, 1986). For example, Plomp (1986) reported that for elderly listeners a 1 dB improvement in SNR for the Dutch sentences equates to an improvement of approximately 18% in percentage-correct scores. These results indicate that measures of speech recognition in quiet may not be predictive of an individual listener's ability to understand speech in noise. One shortcoming of this investigation, however, is the heterogeneity of the geriatric subjects examined. That is, since the subjects exhibited a wide range of degree and configuration of SNHL, audiometric thresholds may account for some of the variability in speech-recognition performance seen in Figure 1.

To control for the potential effects of audiometric threshold on speech-recognition performance, Crandell (1991) examined speech recognition in 26 elderly listeners with similar degrees of mild-to-moderate, high frequency SNHL consistent with presbycusis. Speech-recognition ability was assessed with the SRT procedure using the Predictability-High (PH) sentences from the revised Speech Perception in Noise (SPIN) test (Bilger, 1984; Kalikow, Stevens, & Elliott, 1977). The multi-babble recording derived from the SPIN test, presented at a level of 75 dB SPL, served as the noise competition. All stimuli were presented monaurally to the subject. Results from this investigation indicated an extremely poor relationship ($r = -0.03$; $p < .01$) between speech-recognition ability in quiet and in noise. These data suggest that elderly individuals with similar audiometric configurations may demonstrate varying degrees of speech-recognition susceptibility to noise. An illustration of individual susceptibility for two subjects is presented in Figure 2. Although both subjects obtained essentially equivalent recognition scores in quiet (42.4 dB; 42.7 dB), relatively large individual differences (9.2 dB) were noted for speech-recognition performance in noise. Data for normal-hearing subjects have indicated that a 1 dB change in SNR for

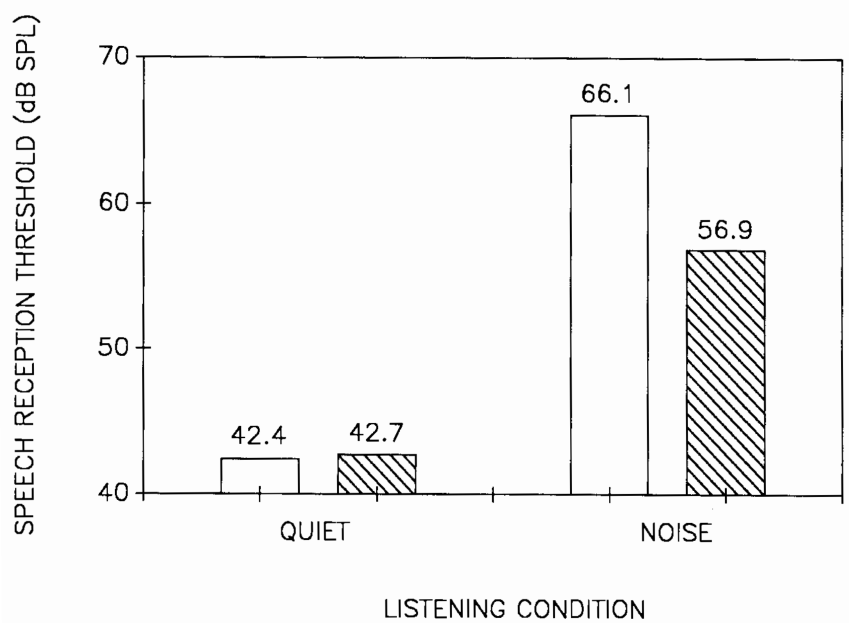

Figure 2. Mean Speech Reception Thresholds (SRTs) in quiet and in noise (noise level = 75 dB SPL) for two elderly hearing impaired subjects (subject #3 denoted by open bar, subject #7 designated by hatched bar).

the SPIN sentences equates to an improvement of 7%-9% in percentage-correct scores (Crandell, 1991). Such individual susceptibility to noise may have important implications for amplification. That is, subjects demonstrating higher degrees of speech-recognition susceptibility to noise may benefit less from conventional amplification strategies which do little to enhance the SNR of the listening environment.

The results of the aforementioned investigations suggest that measures of pure-tone sensitivity, and/or speech-recognition in quiet, may not be not predictive of an elderly individual's ability to understand speech in adverse listening environments. These data suggest that the auditory processes responsible for speech perception in noise are, at least partially, independent from those mechanisms that contribute to absolute threshold. In support of this assertion, a number of physiological, histological, and psychoacoustic investigations have demonstrated a relatively poor relationship between cochlear and/or central pathology and pure-tone hearing sensitivity (e.g., Dolan, Bredberg, Ades, & Neff, 1971; Eldredge, Mills, & Bohne, 1973; Findlay, 1976; Findlay & Denenberg, 1977; Henderson, Hamernik, & Sitler, 1974; Nelson & Turner, 1980; Pickles, 1986; Salvi, Henderson, Hamernik, & Ahroon, 1983; Turner & Nelson, 1982). Therefore, diagnostic procedures other than the pure-tone audiogram must be incorporated into the clinical test battery in order to identify those elderly individuals at greater risk for speech-recognition difficulties in adverse listening conditions. For a discussion on potential revisions in the clinical test battery to identify listeners at risk for speech-recognition difficulties, the reader is directed to Ochs (1990).

HYPOTHESES FOR SPEECH-RECOGNITION DEFICITS IN THE ELDERLY LISTENER

To date, several hypotheses have been offered to explain the speech-recognition deficits in elderly listeners. One possible explanation for these perceptual deficits is reduced physiological processing caused by age-related changes in the cochlea (e.g., Bonding, 1979; Dreschler & Plomp, 1980, 1985; Leshowitz, 1977; Margolis & Goldberg, 1980; Patterson, Nimmo-Smith, Weber, & Milroy, 1982; Plomp, 1978; Tyler, 1986; Tyler, Wood, & Fernandes, 1982, 1983). Plomp (1978) has proposed that hearing impairment mediates its effect on speech recognition by attenuation and distortion. Attenuation, resulting from the elevation of the auditory threshold, causes sound energy to fall below an individual's audible region, thereby not contributing to recognition. Distortion causes difficulty understanding speech that is within the audible region of the individual. Such distortion may be caused by deficits in frequency resolution, temporal resolution, frequency discrimination, and/or intensity discrimination. Speech recognition difficulty in noise is assumed to be due primarily to this distortion component. A number of investigations have reported significant relationships between these cochlear phenomena and speech-recognition deficits in noise within both hearing impaired and elderly populations (e.g., Bonding, 1979;

Chung, 1981; Florentine, Buus, Scharf, & Zwicker, 1980; Gagné, 1988; Horst, 1987; Irwin & McAuley, 1987; Leshowitz, 1977; Margolis & Goldberg, 1980; Moore & Glasberg, 1987; Patterson et al., 1982; Trees & Turner, 1986; Turner, Holte, & Relkin, 1987; Tyler et al., 1982, 1983).

A second hypothesis is that speech-recognition deficits in elderly listeners reflect, in part, central auditory processing disorders. To explain, in the aged hearing-impaired ear the degraded signal from the cochlea is processed through a central auditory system which can neither make fine phonemic discriminations, nor make use of the redundancy of speech, both of which are required for optimum speech recognition (Arnst, 1985; Bergman, 1980; Konkle, Beasley, & Bess, 1977; Orchik & Burgess, 1977; Stach, 1990). Previous investigations have demonstrated that individuals with central auditory lesions tend to perform more poorly on measures of speech understanding which stress the auditory system, such as time-altered, compressed, interrupted, and/or dichotically presented speech (e.g., Konkle et al., 1977; Marston & Goetzinger, 1972; Orchik & Burgess, 1977; Schmitt & Carroll, 1985).

In addition to the peripheral auditory system's contribution to speech recognition, a third hypothesis is that deficits in cognitive function (i.e., learning and retention, memory, problem solving, or reasoning) may exacerbate speech-recognition difficulties (CHABA Working Group on Speech Understanding and Aging, 1988; van Rooij & Plomp, 1990; van Rooij, Plomp, & Orlebeke, 1989). For example, a deficiency in short-term memory could influence speech-recognition tasks requiring the individual to repeat all, or a portion of, what has just been perceived. A recent investigation by van Rooij and Plomp (1990) indicated that one-third of the variance in speech-recognition scores obtained by elderly listeners could be accounted for by cognitive factors, such as processing efficiency and memory capacity. Other investigations, however, have not reported significant contributions of cognitive function to speech-recognition deficits (Jerger et al., 1989; Stach et al., 1985).

A final hypothesis is that speech-recognition performance in elderly listeners *can* be explained by models of audibility alone. An audibility hypothesis suggests that if the speech spectrum is amplified to a satisfactory sensation level, the majority of speech-recognition deficits will be eliminated. To evaluate this hypothesis, investigators have compared the speech recognition of hearing-impaired listeners to that of normal hearers with hearing loss simulated by spectrally-shaped masking noise (Fabry & Van Tasell, 1986; Humes, Dirks, Bell, & Kincaid, 1987; Humes, Espinoza-Varas, & Watson, 1988; Zurek & Delhorne, 1987). A review of such investigations suggests that normal hearers with simulated hearing loss often demonstrate speech-recognition scores (in percent correct) similar to those of matched hearing-impaired listeners. Error patterns for the listeners with simulated losses, however, are frequently dissimilar to those of the hearing-impaired subjects. Additional investigators provide support for an audibility hypothesis through computational models, such as the Articulation Index (AI) and Speech Transmission Index (STI) (French & Steinberg, 1947;

Fletcher & Galt, 1950; Humes, 1991; Humes, Dirks, Bell, Ahlstrom, & Kincaid, 1986; Humes & Roberts, 1990; Kamm, Dirks, & Bell, 1985; Pavlovic, 1984). A review of these investigations indicates that while such models predict speech recognition with a moderate degree of success, particularly in hearing impaired and elderly persons with mild-to-moderate degrees of SNHL, a number of patients still exhibit greater difficulty understanding speech than these indices would predict.

REHABILITATIVE IMPLICATIONS

Clearly, a number of mechanisms may contribute to reduced speech understanding in the elderly individual and their interactions may be complex (CHABA Working Group on Speech Understanding and Aging, 1988; Crandell, 1991; Plomp, 1986; van Rooij & Plomp, 1990). Rehabilitation strategies for the elderly individual should differ depending on which deficit(s) an individual may exhibit. For example, elderly listeners with pronounced deficits in cochlear, central, and/or cognitive processing may have a poorer prognosis for conventional hearing aid usage, particularly in degraded listening environments (Crandell, 1991; Duquesnoy & Plomp, 1980; Plomp, 1978, 1986). Specifically, conventional analog amplification, which simply amplifies the incoming signal, will not be able to overcome suprathreshold distortions resulting from physiological deficits in the cochlea or central auditory system. Conventional amplification strategies also may not be able to overcome deficits in cognitive processing (CHABA Working Group on Speech Understanding and Aging, 1988; van Rooij & Plomp, 1990). Several investigators have, in fact, reported that for many hearing-impaired listeners conventional amplification may be of limited benefit in a background of noise, and indeed may make the situation worse (Duquesnoy & Plomp, 1980; Haggard et al., 1987; Moore, 1978; Plomp, 1978, 1986; Stach et al., 1985). Hence, alternative amplification strategies such as assistive listening devices (i.e., Frequency-Modulation systems) or sophisticated signal-processing schemes (i.e., noise reduction circuitry) which attempt to improve the SNR of the listening environment, and greater emphasis on speechreading training, may prove to be more appropriate rehabilitative recommendations for listeners with reduced cochlear, central, and/or cognitive processing (Crandell, 1991; Plomp, 1986; Stach, 1990; Stach et al., 1985).

It is reasonable to assume that only through detailed analysis of how the individual auditory system processes various parameters of auditory information in difficult listening environments can maximum rehabilitative benefit be achieved for the elderly listener. That is, to successfully prescribe amplification devices for the elderly hearing-impaired listener, the specific auditory and/or cognitive deficit of the individual must first be identified. The parameters of the amplification system can then be specified according to these measurements. To date, however, there is a paucity of clinical procedures to isolate those mechanisms responsible for speech-recognition difficulties in the individual listener. The development of such procedures is of paramount importance, particularly with the recent advent of digital amplification systems in which the acoustic signal can be accurately modified by a microcomputer prior to output. With proper individual assessment, digital amplification systems should also be capable of benefiting the elderly listener with reduced cochlear and/or central processing (Crandell, 1991; Levitt, 1987; Studebaker, Sherbecoe, & Matesich, 1987). Perhaps since the AI and STI (Humes, 1991; Humes et al., 1986; Humes & Roberts, 1990; Pavlovic, 1984) can predict the speech-recognition performance of some individuals, such indices could be used as a screening procedure to isolate those elderly individuals needing suprathreshold and/or cognitive assessment. Clearly, ongoing collaboration and research among clinical audiologists, psychoacousticians, psychologists, digital engineers, and speech scientists is required in order to develop cost-effective clinical procedures to identify the specific processing deficits of the individual elderly listener.

CONCLUSIONS

The preceding review of literature has highlighted several salient points concerning the speech-recognition abilities of elderly listeners. First, research has shown that elderly listeners with similar audiometric configurations may demonstrate varying degrees of speech recognition in adverse listening environments. An increased susceptibility to noise may not only deleteriously influence communicative efficiency, but also may affect psychosocial aspects of the individual. To date, the physiological origins of these speech-recognition difficulties are uncertain. Hypotheses for these deficits include cochlear, central, and/or cognitive dysfunction. Presumably, in many elderly individuals, speech-recognition deficits are the result of a complex interaction of loss of pure-tone sensitivity and deficits in suprathreshold and/or cognitive processing. To offer optimum benefit to the elderly individual, cost-effective clinical procedures must be developed to identify those mechanisms responsible for speech-recognition difficulties. Through the development of such diagnostic procedures, audiologists presumably will be able to implement more appropriate amplification and rehabilitative strategies for the individual elderly listener.

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