AUDITORY PROCESSING IN AGING LISTENERS

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Many aspects of auditory processing in aging listeners are poorly understood. Methodological problems encountered with the aging population, ranging from ear canal collapse to a conservative criterion, have rarely been considered in past research. The relation between pure-tone thresholds and other aspects of auditory functions is unclear. There have been few studies of frequency and temporal analysis in aging listeners. There is disagreement on the effect of age on speech discrimination abilities in various listening conditions, and the cause of speech perception problems in aging listeners has not been adequately investigated. Areas of importance for clinical consideration and auditory research with aging listeners are discussed.

Early studies of the effects of aging on hearing were concerned primarily with documenting the amount of hearing loss occurring at various frequencies (e.g., Bunch, 1929; Bunch, 1931; Steinberg, Montgomery, & Gardner, 1940). Although pure-tone thresholds have frequently been used to define auditory handicap, this definition ignores the fact that speech discrimination ability is dependent on supra-threshold processing. Speech discrimination abilities as a function of aging were later measured using both normal and distorted speech tasks (e.g., Pestalozza & Shore, 1955; Calearo & Lazzaroni, 1957). Over the past twenty years, additional data on age-related hearing loss have been compiled with continued focus on the loss of threshold sensitivity and the reduction of speech discrimination ability. From these data, the composite picture of hearing in the elderly appears to be a gradually progressive sensorineural hearing loss, usually worse for high frequencies but sometimes of equal magnitude across all frequencies, and speech discrimination skills are poorer than would be predicted for the amount of hearing loss, especially in difficult listening situations.

Anatomical changes due to aging have been found throughout the auditory system. A loss of stiffness in the cartilaginous portion of the external auditory meatus becomes a problem only when an earphone is placed on the pinna. Arthritic middle ear joints become more prevalent with increasing age (Etholm & Belal, 1974; Harty, 1953) but apparently have no effect on hearing sensitivity (Etholm & Belal, 1974). The hearing problems in elderly listeners are caused by changes in the cochlea, eighth nerve, central auditory nervous system (CANS), or central nervous system in general (CNS). Since performance is often decreased on various tests of central auditory function and CANS degenerative anatomical changes are often found post-mortem in the elderly (Brody, 1955; Dayan, 1978; Hansen & Reske-Nielsen, 1965; Kirikae, Sato & Shitara, 1964; and Konigsmark & Murphy, 1972), any disproportionate problems with speech perception are usually attributed to CANS degeneration. Central auditory factors undoubtedly play an important role in the speech discrimination problems of elderly listeners, particularly on difficult tasks. However, a distinction should be made between "central" as referring to the CANS (for example, binaural hearing) and cognitive factors that are more central than the brainstem. These distinctions have not been explicit in the literature. Even though these central factors may contribute to speech discrimination problems, the contribution of peripheral factors beyond threshold sensitivity is unknown.

The following hypotheses should be kept in mind in our interpretation of data using elderly listeners: (1) Aging listeners are really no different than young listeners with hearing losses of the same degree; (2) Aging listeners will show additional problems in comparison with younger listeners with similar hearing losses due to: (a) a peripheral problem associated with presbycusis that is not completely described by pure-tone thresholds; (b) a CANS problem; (c) a cognitive difference; or (d) a combination of the above. Audiologically, we are presented a classical site of lesion dilemma, which is complicated by the fact that presbycusis may represent several different types of disorders, as will become apparent in the following review. No present test battery will allow for clear-cut distinctions among the relative contributions of pathology at the cochlea, eighth nerve, CANS, and CNS, but these distinctions are important conceptually for our understanding of auditory processing problems in aging listeners.

The results of auditory experiments using elderly listeners are summarized in order to provide an overview of how the aging process affects various auditory measures. This summary of past research should give us a better understanding of possible underlying processes, help to better interpret clinical test results, and delineate
areas for future research. Throughout this review, references occasionally are given for comparative purposes to studies using young listeners with cochlear hearing loss. Etiological factors are reviewed only insofar as they relate to specific aspects of hearing. A thorough review of etiological factors can be found in recent publications (Feldman & Vaughan, 1979; Gilad & Glorig, 1979; Johnsson & Hawkins, 1979; Lawrence, 1979).

Methodological Problems in Past Research

Definition of “Elderly.” In most studies, elderly listeners are defined as age 60 or above. However, the range for being considered elderly ranges across studies from age 40 to age 70. Certainly, individuals in their 40's or even 50's are not usually considered by society as being old. A more reasonable, albeit arbitrary lower age limit for “elderly” would be age 60 or 65. However, the effects of aging may be seen at an earlier age.

Criterion Effects. Craik (1969) and Rees and Botwinick (1971) have shown that the elderly tend to use a conservative criterion on auditory tasks for yes/no paradigms, and Potash and Jones (1977) found similar results using a confidence rating scale paradigm for elderly subjects having either normal or reduced sensitivity. Therefore, in studies where criterion-free procedures were not used, it is not known whether poorer performance of the elderly was due to a deteriorated sensory system or a conservative criterion. Criterion-free measures, such as forced-choice psychophysical procedures, have rarely been used in assessing the auditory performance of the elderly.

Because most standard audiological tests do not employ forced-choice procedures, it is expected that a young listener would report hearing a signal at a lower intensity than would an elderly listener with equal hearing sensitivity but a more conservative criterion. For speech discrimination tasks, a conservative criterion might result in the listener refusing to respond to words that were unclear. Research is needed to determine whether the use of conservative criteria by the elderly significantly influences auditory test results. If so, a modification of test procedures is needed. Obviously, if a conservative criterion is an important factor in auditory measures using elderly listeners, a whole body of literature, including aging norms, is in error.

Ear-Canal Collapse. Hearing sensitivity has been measured repeatedly as a function of age, and an abundance of normative data exists in this area. However, there are some basic problems in determining the amount of hearing loss due to presbycusis. Since many elderly people have cerumen-impacted ear canals (Fisch, 1978; Schow, Christensen, Hutchinson, & Nerbomme, 1978; Zucker & Williams, 1977), an otoscopic examination is necessary to assure that threshold levels ascribed to presbycusis are not confounded by an obstruction in the ear canal. Many studies do report performing otoscopic examinations prior to pure-tone testing to check for impacted cerumen or otologic abnormalities.

However, no normative study to date has controlled a second problem, ear canal collapse under earphone pressure. Schow and Randolph (1979) classified listeners as having ear canal collapse if there was a 15 dB or greater improvement in threshold at any frequency with circumaural rather than supraural earphones. The incidence of ear canal collapse in their elderly population, age 60-79, was 36%. Even higher percentages have been reported by Zucker and Williams (1977) and Schow and Goldbaum (1980) for elderly nursing home residents, who presumably show greater effects of aging than do ambulatory elderly individuals living outside of nursing homes. Ear canal collapse may explain the high frequency conductive hearing loss found in some studies (Glorig & Davis, 1961; Nixon, Glorig, & High, 1962; Rosen Plester, El-mofty, & Rosen, 1964) which was especially pronounced by age 80. Sataloff, Vassallo, & Menduke (1965), however, did not find this high frequency conductive hearing loss in their elderly subjects. Because ear canal collapse was not considered in some of the early data, present norms may be inaccurate, especially for the higher frequencies in older listeners. Whether or not our present norms are valid, all elderly listeners should be assessed for ear canal collapse and corrective measures taken (such as a pad placed between the pinna and ear, ear canal insert, hand-held earphone, etc.) to insure that the magnitude of presbycusis hearing loss is not confounded by measurement artifact.

Nature of Presbycusis Hearing Loss. Another problem in establishing norms is the separation of hearing losses caused by aging from hearing losses caused by other factors, such as noise and disease (Corso, 1976; Johnsson & Hawkins, 1979; Lowell & Paparella, 1977). Usually extraneous factors are partialled out on the basis of case history, and thus many errors are possible. In addition, there is disagreement about the definition of presbycusis. Rosen, Bergman, Plester, El-mofty, and Satti (1962) found good hearing throughout old age in a Sudanese tribe, the Mabaans, and attributed their good hearing to an environment free of noxious noise and stress. Kapur and Patt (1967) found similar results for the Todas in India. While there are many elderly people in the United States who have hearing sensitivity equal to the Ma-baans, the majority show poorer hearing for high frequencies with advancing age (Bergman, 1966). The difficulty in eliminating the effects of noise can be illustrated by Corso’s (1963) normative data. Subjects were excluded on the basis of either extensive military service or environmental noise exposure. Nonetheless, women showed better hearing sensitivity than men, especially at high frequencies. Certainly one interpretation is that regardless of their self-report, men are exposed to more noise than women in our society. However, factors other than noise could contribute to the men’s poorer hearing. For example, a diet rich in saturated fats, with resultant hyperlipidemia, arteriosclerosis, and coronary heart disease, may cause sensorineural hearing loss (Rosen & Olin, 1965; Rosen, Olin, & Rosen, 1970; Spencer, 1973). Weston (1964) found that the factors most related to presbycusis hearing loss in people who for the most part
had negative noise-exposure histories were smoking, arteriosclerosis, circulatory disturbances, high blood pressure, anemia, and deterioration of the other senses (sight, taste, and smell). Weston found that women show more evidence of presbycusis than men, but his sample came from a hearing-aid clinic, and thus would not be representative of the general population. Weston also found that persons with mild presbycusis hearing losses tend to have few of these medical factors, while persons with more severe presbycusis hearing losses tend to have several of the contributing factors. This finding suggests a synergistic relationship between health-related factors and presbycusis hearing loss.

The question remains as to whether these hearing losses should be labeled as presbycusis. Most would agree that they should, but another viewpoint (Lowell & Paparella, 1977; Paparella, 1978) is that the term presbycusis should be used only for those rare cases with no other possible contributing factors so that the loss can be ascribed solely to aging. Paparella (1978) proposed that many hearing losses developing in middle age are genetic in origin, especially those with a flat audiometric configuration. Corso (1963) showed that decreased hearing begins at about age 32 in men and age 37 in women. Berger, Royster, and Thomas (1977) suggested an even younger age of onset. We can only conclude that the hearing loss associated with aging begins at an early age, and that the contributing factors are extremely difficult to determine. Accordingly, most studies define presbycusis subjects as being over a specified age with a bilateral, acquired, sensorineural hearing loss of gradual onset, unrelated to history of ear disease or noise exposure.

While this definition may be pragmatic for research purposes, clinical audiologists must always be alert to medical factors other than biological aging. Rosen et al. (1970) and Spencer (1973) have shown that hearing loss due to hyperlipidemia can be alleviated by a change in diet, and Shea (1975) has found that excessive smoking, excessive salt intake, and diabetes also may relate to fluctuating sensorineural hearing loss. Elderly people with sensorineural hearing loss should be referred to an otolaryngologist who is sensitive to the hearing characteristics of the elderly for a thorough medical examination.

Pure-tone Thresholds

Audiometric Configuration in Relation to Etiology.

The characteristic presbycusis deficit seen in all normative data is a gradually sloping, high-frequency hearing loss. The loss increases gradually at first and then accelerates more rapidly with increasing age, especially for the higher frequencies (Berger et al., 1977; Corso, 1963; Glorig & Nixon, 1960; Glorig & Nixon, 1962; Glorig & Roberts, 1965; Robinson & Sutton, 1979; Spoor, 1967), and is bilaterally symmetrical (Dayal, Kane & Mendelson, 1970; Klotz & Kilbane, 1962; Sataloff & Menduke, 1957). However, not all presbycusis hearing losses follow the typical audiometric configuration. Dayal et al. (1970) found a 31% incidence of flat audiometric configurations in a presbycusis sample. Schuknecht (1964, 1974, 1975) has described four different types of presbycusis (sensory, metabolic or strial, mechanical or cochlear conductive, and neural) and has related etiology to audiometric configuration. Sensory presbycusis is characterized by an abrupt high frequency loss; metabolic presbycusis is indicated by a flat audiometric pattern; mechanical presbycusis is associated with a gradually sloping high frequency loss (the configuration seen in the normative data), and neural presbycusis is implicated when speech discrimination ability is poorer than would be expected from the audiogram. Schuknecht’s evidence, however, appears to be based on case studies rather than statistical analyses using large numbers of subjects, and Suga and Lindsay (1976) have questioned whether a particular audiometric configuration indicates a specific type of cochlear lesion in the elderly. Johnson and Hawkins (1979) and Lawrence (1979) have also expressed reservations about Schuknecht’s anatomical descriptions. Nevertheless, some sort of audiometric classification may provide the basis for a useful model to describe threshold and supra-threshold auditory data. However, more than one type of anatomical degeneration may occur concurrently. An individual’s audiometric pattern does tend to stay the same over time, even as the hearing loss progresses (Dayal & Nussbaum, 1971).

Hearing Loss and Handicap. Surjan, Devald, and Pal-falvi (1973) reported the most common causes of hearing loss across all age groups to be presbycusis, noise-induced hearing loss, and chronic middle ear disorder. The aging person may well have hearing loss from all three causes. Estimates of the proportion of retirees who have hearing difficulties range from 10% to 60% (Fisch, 1978; Powers & Powers, 1978; Rupp, 1979). Much of the difficulty in incidence estimates is due to the difficulty in determining the minimum hearing loss which causes a hearing handicap. Plomp (1978) suggested than an average hearing loss of 24 dB HL across 500, 1000, and 2000 Hz is the lower limit of hearing handicap. Using this definition, he showed that at the age of 65, 24% of the population is handicapped; over 50% by age 70, and 50% by age 75. Using a similar definition, Schow and Nerbonne (1980) found an 82% incidence in elderly nursing home residents. Plomp’s definition of handicap, however, may be inappropriate because it does not include the predominant audiometric configuration of presbycusis and noise-induce hearing loss, i.e., good low-frequency hearing sensitivity with increasingly poor high-frequency sensitivity. Liden (1967) and Aniansson (1974) have demonstrated that persons with high-frequency hearing losses are handicapped in noisy situations, even if their hearing for 500, 1000, and 2000 Hz is entirely normal. Thus, Plomp’s percentages may underestimate the percentage of elderly individuals who are auditorily handicapped. Similarly, Leshowitz (1979) has concluded that speech perception in noise deteriorates at lower thresholds than Plomp’s 25 dB, especially in elderly listeners. Also, speech-reading skills are worse in the elderly (Ewertson & Nielson, 1971; Pelson &
A discussion of the differences between these studies, as reflex thresholds for white noise in the elderly subjects. normal hearing adults, but found increased acoustic-thresholds for pure tones between young and elderly (1979a), however, found no differences in acoustic-reflex thresholds and is the reciprocal of impedance (difficulty of energy flow at the ear). Acoustic Immitance

Several investigators have found that the middle ear system becomes increasingly compliant up to middle age and then stiffens with further aging (Alberti & Kristensen, 1972; Jerger, Jerger & Mauldin, 1972). In agreement with these results, Blood and Greenberg (1977) found decreasing admittance with increasing age in subjects age 50 and older. Beattie and Leamy (1975), however, found admittance to be higher in their elderly (age 60-78) as compared to their younger (age 17-29) group. Their older group consisted entirely of males, however, while the younger group was composed primarily of females. Several studies have shown that women have lower acoustic admittance than men (Blood & Greenberg, 1977; Hall, 1979; Jerger et al., 1973; Nerbonne, Bliss & Schow, 1978). Some investigators have shown no immitance changes as a function of aging (Nerbonne et al., 1978; Thompson, Sils, Recke, & Bui, 1979). Importantly, Thompson et al.'s subjects had a thorough otoscopic examination and were included as subjects only if the eardrum had normal "shape, color, light reflection, translucence" and "absence of scar tissue, tympanosclerosis, and excess moisture." Since no age-related immitance changes were seen in their study, tympanic membrane changes might account for the decreased admittance seen with aging by other investigators.

In all of these studies, subjects had either normal hearing or sensorineural losses. However, if middle ear changes with aging do indeed cause conductive hearing losses (Glorig & Davis, 1961; Nixon et al., 1962), immitance measurements also should be made as subjects only if the eardrum had normal "shape, color, light reflection, translucence" and "absence of scar tissue, tympanosclerosis, and excess moisture." Since no age-related immitance changes were seen in their study, tympanic membrane changes might account for the decreased admittance seen with aging by other investigators.

There currently is disagreement about the effect of age on acoustic-reflex thresholds. Jerger et al. (1978) found decreased acoustic-reflex thresholds for pure tones and no change in acoustic-reflex thresholds for white noise with increasing age in normal-hearing subjects. Silman (1979a), however, found no differences in acoustic-reflex thresholds for pure tones between young and elderly normal hearing adults, but found increased acoustic-reflex thresholds for white noise in the elderly subjects. A discussion of the differences between these studies, as well as a review of much unpublished data, can be found in Jerger (1979) and Silman (1979b). Thompson, Sils, Recke, and Bui (1980) found no changes in acoustic reflex thresholds for either pure tones or filtered white noise as a function of age for normal-hearing adults, but did find decreased growth of the acoustic reflex to these stimuli with increasing age.

Loudness and Adaptation

Growth of Loudness and SISI Test. Growth of loudness is of particular interest in elderly listeners since recruitment is found with cochlear lesions while absence of recruitment is a retrocochlear sign. The alternate binaural loudness balance (ABLB) test cannot be used for listeners with presbycusis since their hearing loss is bilaterally symmetrical, and other tests of recruitment have given equivocal results. Recruitment was measured by Pestalozza and Shore (1955) and Harbert, Young, and Menduck (1966) in elderly subjects using the monaural bi-frequency loudness balance (MLB) test. Both studies found many elderly subjects who did not show recruitment on this particular test. The accuracy of the MLB test, however, depends on the assumption that recruitment is not present for the low frequency reference and that subjects are able to quickly perform loudness matches between widely different frequencies. Other than attempting to use uncomfortable loudness thresholds as a recruitment measure, there is no behavioral test of recruitment for elderly listeners.

Jerger, Shed, and Harford (1959) found a wide range of Short Increment Sensitivity Index (SISI) scores in presbycusic patients, unlike the consistently high scores found at high frequencies for listeners with similar amounts of hearing loss due to noise trauma. However, other studies have shown no differences between presbycusis and various cochlear etiologies for SISI scores across a range of sound pressure levels (Young & Harbert, 1967) or at high levels (Konig, 1969). Since the SISI test would be greatly affected by a conservative response criterion, this test may be especially inappropriate for the elderly.

Although acoustic reflex SL presumably measures recruitment, Bergholtz, Hooper, and Mehta (1977) found little agreement between the recruitment indices of acoustic reflex SL and electrocochleographic input-output curves and also found no consistent pattern of recruitment in listeners with presbycusis hearing loss. Jerger (1973) found no difference in the speech discrimination scores of recruiting and non-recruiting elderly listeners, using SL level of the acoustic reflex as the recruitment measure. The question still remains about whether acoustic reflex thresholds are measuring loudness, and further research is needed to determine the relation between acoustic reflex sensation level and loudness before we can draw any conclusions.

Adaptation. Adaptation can be measured clinically using Bekesy audiometry or tone-decay tests. Bekesy tracings are usually Type I or II (normal or cochlear site
of lesion) for presbycusic subjects (Harbert et al., 1966; Jerger, 1960; Jokinen, 1969, 1970), and show no abnormal fatigue. Forward vs. backward Bekesy tracings likewise do not show evidence of abnormal fatigue (Jokinen & Karja, 1970). The amount of adaptation usually seen on clinical tone decay tests is 30 dB or less (Gang, 1976; Gjaevenes & Sóhoel, 1969; Goetzinger, Proud, Dirks, & Embrey, 1961; Harbert, Young, & Menduke, 1966; Olsen & Noffsinger, 1974), again consistent with other etiologies associated with a cochlear site of lesion. Willeford (1971) reported abnormal tone decay for only a small number of elderly subjects. Thus, presbycusic subjects usually do not show the abnormal fatigability that would be expected with a retrocochlear site of lesion. It might be important, however, to measure rate as well as amplitude of adaption (Wiley & Lilly, 1980).

**Frequency Analysis**

Auditory analysis of speech signals; e.g., gross pitch characteristics required for perception of emotional characteristics of speech or fine pitch discrimination required for second-formant transitions and identification of certain consonants, clearly is dependent upon frequency analysis. Without good frequency analysis abilities, speech discrimination abilities are impaired (e.g., Gengel, 1973; Linville & Brandt, 1980).

Reviewed below are the effect of cochlear hearing loss for relatively young listeners and for elderly listeners on four measures of frequency analysis: frequency discrimination; psychophysical tuning curves; loudness measures of critical bandwidth (CBW); simultaneous masking.

**Frequency Discrimination.** One of the effects of the cochlear hearing loss is a decrease in frequency discrimination ability both for frequency modulated (FM) signals (Filling, 1958; Meurmann, 1954; Zurek & Formby, 1979) and pulsed sinusoids (Butler & Albrite, 1956; Gengel, 1973; Ross et al., 1965). Also, frequency discrimination tends to be poorer as the hearing loss increases (Ross, Huntington, Newby, & Dixon, 1965; Zurek & Formby, 1979). Meurmann (1954) and Filling (1958) studied frequency discrimination with FM techniques in elderly hearing-impaired listeners. Meurmann found that the DLFs at 20 dB SL for 125-4000 Hz were larger than normal in aging listeners, but certainly were no larger than the DLFs for listeners with Meniere’s disease or young listeners with sensorineural hearing loss. Filling found that the DLFs at 20 dB SL for 125-8000 Hz were worse for older listeners, but these listeners also had the poorest hearing sensitivity. However, the youngest listeners in her presbycusic group had essentially normal hearing sensitivity for low frequencies, yet had slightly increased DLFs at these frequencies. As a result, Filling conjectured that the DLF may show adverse effects on aging even before a loss of hearing sensitivity is observed. Again, a more conservative criterion alone could explain this small increment.

It is now generally recognized that FM measures are assessing more than just frequency discrimination. Jesteadt and Sims (1975), Moore (1976), and Nuetzel, Bilger, Rabinowitz, and Trahoitis (1979) found little agreement between differential sensitivity for frequency modulation and for pulsed sinusoids in normal hearing listeners. This result is not surprising since FM sinusoids have multiple sidebands which vary with time, thus giving the listener a complex stimulus that is both a frequency and a temporal measure. Pulsed sinusoids therefore give a more direct measure of frequency discrimination.

Konig (1957) measured frequency discrimination for pulsed sinusoids that 40 dB SL for 125-4000 Hz with the constant-stimulus method. The listeners ranged from 20 to 89 years with 10 listeners in each decade of age. The older listeners had less sensitive hearing than the younger listeners, but none had hearing losses greater than would be expected from aging norms. The DLFs increased with age, and the overall results were in agreement with Filling’s. Not only did the DLFs increase at high frequencies, which might be expected due to the concomitant decrease in hearing sensitivity, but they also increased at low frequencies, where the change in hearing sensitivity was much less. However, Turner and Nelson (1979) found abnormally large low-frequency DLFs in younger listeners with high frequency, noise-induced hearing loss. In agreement with Konig, Ross et al. (1965) found an increase in DLFs at 30 dB SL for 500, 2000, and 4000 Hz with increasing age, using the method of constant stimuli, although the effect of hearing loss was not accounted for. Both Konig and Ross et al. incorporated very little practice for their subjects prior to the measurements. Moore (1976) found large practice effects for frequency discrimination of pulsed sinusoids for normal hearing subjects, especially for those subjects who gave initially large DLFs.

Thus, all the data on frequency discrimination in elderly listeners have procedural problems. No data exist for an experiment where both practice effects and decision strategies have been controlled. Although measurement of frequency discrimination using pulsed sinusoids is too time consuming to be useful as a clinical test, no other frequency analysis measure assesses such fine discrimination. As mentioned earlier, this fine discrimination ability may be more sensitive than are auditory thresholds to cochlear impairment, and, in addition, impaired frequency discrimination ability is related to impaired speech discrimination ability (DiCarlo, 1962; Gengel, 1973; Ross et al., 1965). Thus, DLFs will continue to be a useful measure for research. Frequency discrimination measures using elderly listeners should control for learning effects, criterion effects, and stimulus complexity.

**Psychophysical Tuning Curves.** The psychophysical tuning curve is another measure of frequency analysis and holds promise as a useful clinical procedure (Thornton & Abbas, 1980; Zwicker & Schorn, 1978). These curves are obtained by fixing the level and frequency of a probe tone and measuring the level of a second tone at
various frequencies required to mask the probe. Psychophysical tuning curves look much like physiological tuning curves of single primary auditory neurons (Zwicker, 1974). They show abnormal broadening, abnormal shape, and loss of the tip in regions of hearing loss (Florentine, 1978; Hoekstra & Ritsma, 1977; Leshowitz & Lindstrom, 1977; Leshowitz, Lindstrom & Zurek, 1976; Tyler, Fernandes, & Wood, 1980; Wightman, McGee, & Kramer, 1977; Zwicker & Schorn, 1978). They can also show abnormalities in regions of normal hearing sensitivity (Mills, Gilbert, & Atkins, 1979; Wightman et al., 1977), especially if there is a sizeable loss for higher frequencies (Nelson, 1979). Zwicker and Schorn (1978) recently published a study with 72 hearing-impaired listeners, 10 of whom had presbycusis or progressive hereditary hearing loss. For the sake of clinical expediency, only six points on the tuning curve were measured. Also, the tuning curve data were normalized, and limited information was reported on the hearing loss of the subjects in the group. Nevertheless, the tuning curves for this group showed greatly reduced frequency selectivity. Again, we would like to know whether this loss in frequency selectivity is the same as would be seen for young hearing-impaired listeners with similar audiograms.

**Loudness Measure of Critical Bandwidth.** CBW measures are another indication of frequency analysis. The usual procedure for obtaining loudness estimates of CBW is to measure loudness summation across frequencies by having the listeners balance the loudness of a pure tone with the loudness of a complex (two or more pure tones or narrow band noise) that is varied in bandwidth. As the bandwidth of the complex is widened, the loudness of the complex remains constant as long as all of the energy in the complex is contained within a critical band. When the CBW is exceeded, energy from adjacent critical bandwidths is summed and loudness increased (Zwicker, Flottorp, & Stevens, 1987).

Bonding (1978) and Bonding, Elberling, Barfod, and Florentine (1978) described a clinical technique for measuring amounts of loudness summation and size of CBW based on loudness balancing methods described earlier by Scharf and Hellman (1966) and Martin (1974). For loudness summation measurements, loudness balances were made between a standard subcritical bandwidth noise and various other noise across a range of intensities. For the CBW measurement, loudness balances were made between a standard subcritical bandwidth noise and various other bandwidths of noise at the level where loudness summation was greatest. Bonding (1979d) found that most of his 20 presbycusis listeners, all with fairly flat audiograms, had normal CBWs, no matter how great their hearing loss. Similarly, normal CBWs were usually found in listeners with hearing losses due to salicylate ototoxicity (Bonding, 1979a), Meniere’s disease (Bonding, 1979b), acoustic neuroma (Bonding, 1979c), and hereditary losses or losses of unknown etiology (Bonding, 1979e). The magnitude of loudness summation was reduced in sensorineural hearing loss, especially in ears with recruitment, and the magnitude of loudness summation varied inversely with hearing loss. Although CBWs for some listeners appeared to be very wide (greater than 1600 Hz at a 1000 Hz center frequency), the listeners often demonstrated loudness summation. Since these two measures should have been identical, the test-retest variability of the CBW measurement may be quite large for individuals with reduced loudness summation. While these clinical loudness summation and CBW measures may provide useful information about groups of listeners, they may not give an accurate measurement of CBW for all of the individuals in the group.

**Simultaneous Masking.** Two aspects of simultaneous masking have been assessed in experiments with elderly listeners. One of these, the critical ratio, is the signal-to-noise ratio at masked threshold. The second, upward spread of masking, is the extent to which the influence of the masker spreads to higher frequencies. Both of these measures are a reflection of critical bandwidth and are suitable clinical measures since they take little time.

Critical ratios are usually found to be normal for listeners with cochlear hearing losses (Jerger, Tillman & Peterson, 1960; Rittmanic, 1962), and appear largely unaffected by level in either normal listeners or listeners with cochlear hearing loss (DeBoer & Bowmeester, 1974; Palva, Goodman & Hirsh, 1953). However, Tyler et al. (in press) found both abnormal critical ratios and a level effect for listeners with high-frequency, noise-induced hearing loss in the region of the loss. Reed and Bilger (1973) also found critical ratios to increase with level for high frequencies for normal-hearing listeners. Margolis and Goldberg (1980) measured critical ratios in five presbycusis listeners for a 1000 Hz tone at 50 dB SPL, varying the pressure spectrum level of a broad-band noise to obtain 60% detection of the tone. Four of the five presbycusis listeners showed abnormal critical ratios; i.e., they needed an improved signal-to-noise ratio in order to detect the tone. One possibility for the abnormal critical ratio is a widened CBW. However, Margolis and Goldberg also measured CBWs using a low-pass noise masker for these same listeners. Since most of the listeners had normal CBWs (in agreement with Bonding, 1979d), they concluded that critical ratios are not a simple reflection of auditory filter bandwidth, at least in elderly hearing-impaired listeners.

Upward spread of masking data are also in conflict with CBW data. In normal-hearing listeners, the spread of masking at low intensities is symmetrical for frequencies above and below the masker. As the intensity of the masker is raised, the influence of the masker spreads out into the higher frequencies. This upward spread of masking appears to be detrimental to speech perception in normal-hearing listeners at high intensities (95-100 dB SPL) (Danaheier, Osberger, & Pickett, 1973). Abnormally broad upward spread of masking has been observed for some but not all listeners with sensorineural hearing losses (DeBoer & Bowmeester, 1974; Jerger et al., 1960; Leshowitz & Lindstrom, 1979; Rittmanic, 1962; Tyler et al., 1980). Martin and Pickett (1970) found upward
spread of masking to be unrelated to degree of hearing loss, but Pick, Evans and Wilson (1977) found auditory filter slopes and bandwidths to be positively correlated with hearing loss. Jerger et al. (1960) tested 20 adults with sensorineural hearing loss and 10 elderly subjects with presbycusis as well as adults with various types of conductive hearing losses. Abnormal spread of masking was observed for adult listeners with cochlear hearing loss and the elderly listeners with presbycusis. However, the elderly listeners did not show greater spread of masking effects than their young counterparts.

Audiologists would like to know whether the difficulty that presbycusis listeners often experience in understanding speech in noise is related to peripheral frequency analysis abilities. Leshowitz and Lindstrom (1979) suggested that this problem is caused by reduced frequency selectivity which is reflected in an abnormal upward spread of masking. Jerger (1973), however, stated that the problem is attributable to impaired central auditory pathways in the elderly. Before any conclusions can be drawn, more data are needed on the interrelationships among various frequency analysis measures and speech perception tasks in noise, both for young listeners with clearly defined auditory pathologies and for elderly listeners.

Temporal Analysis

Many studies have shown that elderly listeners have difficulty in understanding temporally-degraded speech. It is thus surprising that non-speech measures of temporal analysis have received little attention. Temporal processing is often affected by sensorineural hearing loss (Brandt & Caskey, 1978; Cudahy, 1975, 1977; Cudahy & Elliott, 1975, 1976; Elliott, 1975; Fitzgibbons & Wightman, 1979; Hauser, Marr & Colburn, 1979; Nilsson & Liden, 1976; Hawkins & Wightman, 1978). The time constants among various monaural temporal analysis measures (e.g., temporal acuity, nonsimultaneous masking, and temporal integration) vary by two orders of magnitude. The small time constants found for temporal acuity measures (e.g., Green, 1971) would be expected from peripheral filter characteristics (Duifhuis, 1973, 1974). A central mechanism in addition to peripheral processing is implied for the measures with longer time constants, and these measures seemingly reflect an integration process (Zwislocki, 1960). Since peripheral temporal processing underlies all of the more central temporal measures, sensorineural hearing loss may affect most temporal analysis measures. In elderly listeners, temporal integration is the only temporal analysis measure that has received much attention.

Temporal Integration. Short duration signals (less than 200 msec.) require increasingly greater intensity with decreasing duration in order to be detected. This time intensity trading function is termed temporal integration in the psychoacoustic literature and is the basis of brief-tone audiometry in the clinical audiometry literature. Listeners with cochlear hearing losses generally show reduced temporal integration (Elliott, 1963; e.g., Harris, Haines & Meyers, 1958; Olsen et al., 1974; Pedersen, 1973; Sanders & Honig, 1967; Wright, 1968; Tyler et al., 1980) although this generalization has several limitations. Normal-hearing listeners also show shorter time constants at higher frequencies (Watson & Gengel, 1969), individuals with high-frequency hearing loss may not have smaller than normal time constants (Gengel & Watson, 1971; Watson & Gengel, 1969), and intersubject and intrasubject variability is large (Gengel & Watson, 1971; Olsen et al., 1974). Nevertheless, the data from presbycusis listeners (Corso, Wright, & Vallerio, 1976; Pedersen & Elberling, 1973) are indistinguishable from data on younger listeners with cochlear impairments (ototoxicity from salicylates, noise-induced hearing loss, and Meniere’s disease).

Speech Discrimination

Some problems have been found in speech discrimination by elderly listeners in ideal listening conditions, but the largest problems show up under difficult listening conditions such as acoustically-altered speech and speech in a competing-noise background. Audiology continues to assess speech discrimination abilities primarily in ideal listening situations. However, in order to define the problems that many elderly listeners experience in difficult listening situations, clinicians should employ speech discrimination tests that approximate actual listening conditions. If more realistic speech discrimination measures are used we then can better understand our elderly patients’ complaints and can better counsel each individual as to realistic expectations for various speakers and environments. Audiologists should be careful in attributing these test results to CANS problems until we understand the influence of peripheral auditory problems on these measures.

Speech Discrimination in Ideal Listening Conditions. In addition to a loss in absolute hearing sensitivity, the elderly also show a decrease in speech discrimination ability. Due to the relationship between hearing loss and speech discrimination scores in young listeners with cochlear impairment, research has focused on whether the elderly show a greater deficiency in speech discrimination ability than would be predicted from the amount of their hearing loss. Most of the studies in this area have a serious methodological problem. The presentation level of the monosyllable speech stimuli used for speech discrimination testing typically has been 30 or 40 dB above the individual’s threshold for spondaic (bisyllabic) words (Blumenfeld, et al., 1969; Feldman & Reger, 1967; Harbert et al., 1966; Luterman, Welsh, & Melrose, 1966; Palva & Jokinen, 1970; Punch & McConnell, 1969; Surr, 1977). The spondaic word threshold or speech reception threshold (SRT) is highly dependent on lower frequencies (500 to 1000 Hz), especially for ears with sloping hearing losses (Carhart & Porter, 1971). Discrimination of monosyllabic words, which have less redundancy than spondaic words, is dependent on both
high- and low-frequency hearing (French & Steinberg, 1947; Kryter, Williams, & Green, 1963; Mullins & Bangs, 1957; Pascoe, 1975; Young & Gibbons, 1962). Since most listeners with presbycusis have predominantly high-frequency hearing losses, the typical level of 30 or 40 dB above SRT will often underestimate their actual speech discrimination ability. Kasden (1970) and Gang (1976) measured speech discrimination scores as a function of intensity in presbycusis listeners and found that maximum performance was not reached until an average level of 50 dB above SRT for W-22 word lists.

Thus, in order to assess speech discrimination ability in hearing-impaired listeners, the presentation level must be sufficiently intense to overcome the attenuating effect across all frequencies. Relatively few studies have used a reasonable presentation level for elderly listeners. Jerger (1973) studied effects of aging on speech discrimination ability using 4,095 ears from 2,162 listeners, age 6-89 years. Speech discrimination was measured at several intensity levels, and the maximum obtained score for each ear, PB max, was used for all comparisons. Jerger fit an exponential curve to PB max scores (for all degrees of hearing loss combined) as a function of age. The function was similar to that found for hearing loss across age (Hinchcliffe, 1962). Thus, the decrease in PB max with aging is similar to the decrease in absolute sensitivity with aging. Jerger also examined mean PB max scores as a function of age for groups with varying degrees of hearing loss (grouped by pure-tone average). Although the mean data showed much variability, a slight tendency for PB max to decrease with age was observed. However, high-frequency thresholds might have been poorer for the elderly listeners, and small decrements in speech intelligibility would be expected with additional high-frequency hearing loss.

Luterman, Welsh, and Melrose (1966) carefully matched audiograms of listeners with mild-moderate, high-frequency hearing loss and found more errors for elderly (age 79-87, N = 18) than for young (age 20-38, N = 18) listeners on W-22 word lists at 40 dB SL. Surr (1977) also carefully matched audiograms for 100 listeners, age 30-90, with mild high-frequency hearing losses. She found no difference in speech discrimination scores across age groups for NU-6 word lists at 40 dB SL. Kasden (1970) matched the audiograms of 10 young (age 20-40) with 20 elderly (age 60-69) listeners having mild-moderate, gradually sloping hearing losses. W-22 word lists were presented at 10-50 dB SL, and no differences were found between young and elderly listeners at any presentation level. We do not know whether this lack of agreement among studies is due to different audiometric configuration or to other factors.

Bess and Townsend (1977) found age effects in the speech discrimination abilities of 556 subjects (742 ears) with flat hearing losses, age 14-98. For mild hearing losses, mean speech discrimination ability, measured at 40 dB SL, decreased very slightly with age. For greater amounts of hearing loss, speech discrimination decreased dramatically with age. We can conclude that the combined effects of age, amount of hearing loss, and the slope of the loss on speech discrimination skills in the elderly have not been adequately described.

Speech Discrimination for Altered Speech. Speech can be altered in the frequency domain or in the temporal domain. The usual frequency-related alteration is low-pass (LP) filtering, although band-pass filtering has also been used. Temporally related alteration generally is accomplished by a change in speech rate, or by compression, expansion, interruption, or reverberation of recorded speech. Elderly people generally experience difficulty with all types of altered speech (Schow et al., 1978), but there are many inconsistencies across studies.

Discrimination of LP-filtered speech has been measured by Krikka et al. (1964) and Marston and Goetzinger (1972), and discrimination of band-pass filtered speech has been measured by Harbert et al. (1966) and Palva and Jokinen (1970). Marston and Goetzinger did not find differences between young and older listeners. The other studies found poorer performance for elderly than for young listeners. Comparisons among studies are difficult due to subject differences in age, pure-tone sensitivity, and speech discrimination ability for unaltered speech.

The elderly have demonstrated decreased performance on fast speech (Bergman, Blumenfeld, Cascard, Dash, Levitt, & Margulies, 1976; Calearo & Lazaroni, 1957), interrupted speech (Bergman, 1971; Bergman et al., 1976; Krikka et al., 1964; and Marston & Goetzinger, 1972), and reverberated speech (Bergman, 1971; Bergman et al., 1976). There is disagreement about the effects of time-expanded and time-compressed speech. Luterman et al. (1966) and Schon (1970) found that discrimination of time-expanded speech was affected by hearing loss but not by age. Korabic, Freeman, and Church (1975) found poorer performance for elderly listeners in comparison with young listeners. However, the elderly listeners in their study had high frequency sensorineural hearing losses and poorer speech discrimination scores for unaltered speech, and the test words were presented at relatively low S.Ls. Their results, therefore, may have been influenced by the peripheral hearing loss.

Perception of time-compressed speech for elderly listeners with normal hearing sensitivity (thresholds < 15 dB ISO at 250-4000 Hz) has been assessed by Sticht and Gray (1969). Intelligibility deteriorated progressively in comparison with young listeners for increasing time compression. However, only seven listeners were included in each group, and only 15 words were used for each condition. Results of studies using elderly listeners with hearing loss are varied. Luterman et al. (1966) found no differences between young and elderly listeners with similar high-frequency hearing losses, but used relatively low levels of alteration. Schon (1970) found similar performance among older listeners with typical sloping presbycusis hearing losses, older listeners with sizeable hearing losses, and younger listeners with sizeable hearing losses. Sticht and Gray (1969) and Konkle, Beasley, and Bess (1977), however, both found that with increasing time-compression the elderly hearing-impaired sub-
tions.

The effect of hearing loss combined with aging on speech discrimination of altered-speech materials is not clear from the available data. In only two studies (Marston & Goetzinger, 1972; Sticht & Gray, 1969) was hearing sensitivity within normal limits. If these studies are used as a basis, the conclusion would be that age alone does not affect the perception of frequency-altered speech but does affect the perception of temporally-altered speech. However, this generalization is based on a very limited amount of data. Additional altered-speech studies using normally-hearing elderly listeners must be conducted in order to determine whether this generalization is correct.

In listeners with peripheral hearing losses, the problem is much more complex. Harris (1960) demonstrated in young normal-hearing listeners that combinations of various types of distortion resulted in worse speech intelligibility than would be predicted from the simple addition of the distortions. A multiplicative hypothesis was investigated more extensively by Lacroix and Harris (1979) in young normal-hearing listeners using LP-filtered speech to simulate high-frequency hearing loss. They found that the addition of minimal amounts of time compression, temporal interruption, or speech-shaped noise masking to the LP-filtered speech resulted in marked decreases in speech intelligibility, as would be expected from the multiplicative hypothesis. Lacroix and Harris (1979) also used listeners with high-frequency sensorineural hearing losses, and the multiplicative hypothesis again was supported. Thus, the results of many of the altered-speech studies using elderly listeners are difficult to interpret because the peripheral hearing loss could have accounted for these effects. However, the Konkle et al. (1977) mean audiograms across age groups were very similar, and age appeared to have a large effect on the intelligibility of time-compressed speech, especially in the more difficult listening conditions.

Speech Discrimination in Noise. Conflicting results are found for the effects of aging on perception of speech in noise for listeners with relatively normal pure-tone thresholds. Smith and Prather (1971) found a decrement for elderly listeners in comparison to young listeners for speech discrimination of consonant-vowel (CV) nonsense syllables across a range of signal-to-noise (S/N) ratios using broad-band noise. Orchick and Burgess (1977) found a decrement for their older listeners in comparison to young listeners only for their more difficult S/N ratios using synthetic-sentence identification (SSI) with a competing speech masker across a range of message-to-competition ratios (MCRs). Orchick and Burgess' results support the generalization that the elderly show poor performance for increasingly difficult listening conditions, as was found by Sticht and Gray (1969) and Konkle et al. (1977) for time-compressed speech. However, Smith and Prather found that the elderly's decrease in performance relative to young listeners did not appear to accelerate in the more difficult conditions.

Elderly listeners with hearing loss usually show decreased speech discrimination in noise as compared to younger listeners (Findlay & Denenberg, 1977; Jerger, 1973; Jerger & Hayes, 1977; Jokinen, 1973), but young and elderly listeners in these studies may have had different audiometric configurations and amounts of hearing loss. Surr (1977) found no difference in speech discrimination scores in noise among 100 listeners, age 30-90, with matched audiograms, and similar results were reported by Olsen and Garhart (1967) and Tillman et al. (1970) for a smaller sample of listeners whose audiograms were not matched. Even though the mean speech discrimination scores in noise of elderly listeners often are reported to be lower than those of younger listeners, Hayes and Jerger (1979) found that not all elderly listeners show problems with the speech-in-noise task. Similarly, Leshowitz and Lindstrom's (1979) data showed that most but not all listeners with presbycusis hearing losses required increased S/N ratios to understand connected discourse.

Again, peripheral and central factors are difficult to differentiate. Leshowitz and Lindstrom (1979) attributed the difficulty with speech-in-noise that was seen in listeners with hearing losses due to presbycusis, ototoxicity, and noise trauma to a loss of frequency selectivity as measured by upward spread of masking. In their small sample, there was a tendency for the persons with presbycusis hearing loss to show an increased upward spread of masking in comparison to other listeners and concomitantly to need a greater S/N ratio for speech intelligibility. Plomp and Mømpen (1979) also supported a peripheral explanation, and their analysis suggests that the SRT in noise relative to the SRT in quiet may even be better for listeners with presbycusis than for listeners with other sensorineural impairments. Jerger and Hayes (1977), however, attributed the elderly's relative difficulty on the SSI-ICM task to a central auditory nervous system deficiency since the discrepancy between PB max and SSI max follows the same pattern as seen for listeners with central auditory disorders. Comparisons across studies are difficult due to the different speech stimuli, types of noise, S/N ratios, amounts of hearing loss, and ages of the subjects. Also, all elderly listeners should not be expected to perform similarly. Using the SSI MAX-PB MAX comparison on 154 listeners age 60 and older, Hayes and Jerger (1979) found that 40% of the listeners showed primarily peripheral findings; 42% showed central findings; and the remaining 18% of the listeners showed results intermediate between the other two groups.

Binaural Hearing for Speech. Binaural fusion can be used to assess the integrity of the CANS. In this test, speech is filtered into two narrow bands, a high frequency band and low frequency band. A comparison is made between performance for the two bands delivered in the same ear vs. each band delivered to a different ear. The latter condition requires binaural synthesis and is impaired by brainstem lesions and by bilateral and dif-
fusion has been assessed by Harbert et al. (1966) and Palva and Jokinen (1970) using listeners up to age 90. Even though the elderly listeners showed decreased speech discrimination ability on the monaural filtered-speech test in comparison to young listeners, as discussed earlier, binaural synthesis created no additional problem. In fact, Palva and Jokinen commented that the elderly often performed better on the binaural test than on the monaural test, which is suggestive of a peripheral problem. That is, in the monaural condition, the two bands of speech interfere with each other due to the degenerated peripheral system. Franklin (1975) found similar results with young (age 13-23) hearing-impaired listeners.

Binaural interaction can also be assessed by measuring the release of masking or the masking level difference (MLD) that occurs when different signals are presented to each ear. There are a multitude of variations among MLD studies insofar as type of stimulus, masker, and delay used, but results for listeners with presbycusis hearing losses are remarkably similar (Bocca & Antonelli, 1976; Findlay & Schuchman, 1976; Olsen, Noffsinger & Carhart, 1976; Tillman et al., 1973; Warren, Wagener & Herman, 1978). Persons with presbycusis hearing losses show smaller mean MLDs than do normal-hearing listeners, although there is considerable overlap in MLD size between the two groups. While abnormal MLDs are seen in persons with brainstem lesions, Olsen et al. (1976) demonstrated that persons with peripheral impairments showed reduced MLDs, and Guaranta, Cassano, and Cervellera (1978) concluded that MLDs (for 500 Hz tones) were not useful diagnostically to detect central impairment unless peripheral hearing sensitivity was normal. In both studies, 40% to 60% of listeners with presbycusis hearing losses obtained MLDs within normal limits. Although many of the elderly in the MLD studies have had only slight hearing losses, MLDs have not been measured systematically in elderly listeners with normal hearing sensitivity or in young listeners with slight hearing losses. Also, the reduction in the MLD size has not been correlated with pure-tone sensitivity in listeners for any age with bilaterally symmetrical hearing losses of larger magnitude. Thus, peripheral effects on the MLDs are not completely understood, and we do not know whether MLDs are decreased in those elderly listeners who demonstrate no loss in absolute hearing sensitivity. However, it does appear that elderly listeners may perform similarly to young listeners with peripheral lesions.

Methodological Problems Pertinent to Speech Studies. The reason for the inconsistencies found among studies is unclear, but there are many plausible explanations. "Elderly" is loosely defined; "presbycusis" probably represents a variety of disorders; and cognitive effects such as conservative criteria may affect our measurements. Several additional problems occur with speech studies. One problem is that the level of presentation has seldom been adequately controlled. Most studies have used presentation levels of 40 dB SL or less, but, as mentioned earlier, Gang (1976) found that maximal speech intelligibility was not reached until 50 dB SL in most elderly persons. This problem cannot be solved, however, by testing all subjects at high intensities because speech discrimination may decrease at increasingly high SLs. For example, this "rollover effect" has been demonstrated by Gang (1976) for unaltered speech in quiet, and was pronounced in subjects in their 80's. For altered speech, only two studies have tested discrimination in elderly listeners over a wide range of intensities. Kirikae et al.'s (1964) mean data for low-pass filtered speech show a small rollover effect, and Calearo and Lazzoroni's (1957) data for speeded speech rates show pronounced rollover effects for some of the subjects for the most difficult conditions. It can be concluded that the level that speech is assessed relative to the level where maximal speech intelligibility would be obtained may greatly influence the results of speech intelligibility measures. Testing at a fixed SL certainly does not equate functional listening level, as has been the intent.

The amount of hearing loss between young and elderly groups is often a problem, especially for those cases where normal hearing has been defined as 35 dB HL or better. In these cases, the younger listeners will tend to have better hearing sensitivity than the older listeners. Also, subjects are often not matched on speech discrimination between groups in an undistorted control condition, so the older listeners may have poorer speech perception under normal conditions. All these problems become apparent in factorial designs, which most studies have employed. The limitation of factorial designs is that it is exceedingly difficult to match subjects by all potentially relevant factors: age, audiogram, and speech discrimination ability for unaltered speech. A correlational design would be more applicable, and with this design the various factors could be partialed out in order to assess their relative and independent effects. Individual data should also be considered since presbycusis is not a clear-cut etiology, unlike hearing losses caused by noise exposure, ototoxicity, etc. A close examination of individual differences may give us important clues about possible sub-groups of presbycusis.

**CONCLUSIONS**

From the review of hearing in aging, it is apparent that the effects of aging on auditory processing are not understood. The literature presents a confusing picture of elderly people's auditory problems. Earlier in this paper, we set forth hypotheses about auditory processing in elderly listeners. Some studies support the hypothesis that there is no difference between young and elderly listeners while other studies show worse performance in the elderly. This poorer performance appears sometimes due to peripheral factors and at other times due to CANS or cognitive factors. Unfortunately, most studies treat the elderly as one group, about whom one generalization must be made. More realistically, elderly individuals with presbycusis hearing loss may have different
pathologic conditions at different sites of the auditory system. That is, according to a perceptive reviewer, "the heterogeneity of results may be attributable to a heterogeneity of pathologic conditions that results in a conglomerate of subgroups who have only one thing in common—age."

In spite of individual differences, however, some generalizations can be made. It is known that absolute hearing sensitivity decreases with increasing age in most individuals. Also, speech discrimination for easy speech tasks in quiet environments roughly parallels the decrement in absolute hearing sensitivity if all presbycusis listeners are regarded as one group. This generalization, however, may not apply to specific audiometric configurations. Difficult listening conditions often but not always result in a larger decrement in speech discrimination scores for older as compared to younger listeners. It is not known to what extent a filter model would explain some of these difficulties, but results from many studies suggest that aging in some way causes greater distortion of auditory signals than would be expected from the hearing loss. It is important to note that the conditions typically used in audiological assessment of speech intelligibility are not realistic in this regard. In actual everyday listening situations, competing noise is often present, speakers talk at fast rates in reverberent rooms, and telephones limit the spectrum of the speech signal.

Little is known about peripheral analysis abilities of elderly listeners, including whether their frequency analysis abilities are the same as for young listeners with similar hearing levels, or whether an additional loss of frequency specificity occurs with aging. In addition, there are few data on relationships among measures of frequency selectivity in the same individual. Very limited data exist on the relation of frequency analysis to speech discrimination for listeners of any age, and most of these studies have used frequency discrimination as the frequency-analysis measure.

Research is still needed on auditory processing in elderly listeners. Of ultimate importance is how measures of peripheral analysis relate to speech-perception abilities, both in quiet and in noise. On the basis of these tests, different patterns may emerge among various listeners which would provide useful information, both theoretically and diagnostically. A determination of the effect of cognitive factors on clinical tests, both for speech and non-speech measures also should be made. Pertinent cognitive factors might be criterion effects, effects of training, and stimulus uncertainty. If these cognitive factors indeed influence the outcome of our clinical measures, we may need to modify our test procedures for elderly listeners.

The ability to separate peripheral from central deficits and to describe the type of peripheral or central processing problem that exists in each individual is needed. This knowledge would enable us to provide more efficient and more individualized rehabilitation for elderly individuals with auditory deficits. If an individual's auditory problem is primarily peripheral, signal-processing techniques such as frequency lowering and amplitude compression incorporated into new hearing-aid designs may prove useful in maximizing speech perception. If an individual also demonstrates CNS problems, however, it is unlikely that these problems can be compensated for with signal-processing techniques. If an individual demonstrates cognitive problems, rehabilitative procedures might incorporate training to remediate these deficits.

The communication problems of the elderly are beginning to be emphasized by members of ASHA, as indicated by the June, 1980, issue of ASHA, which focused on aging and communication. Much of the current activity relates to service delivery, which of course is of paramount importance. However, in order to improve the quality of services to the elderly, our profession needs to better understand the auditory processing problems of elderly individuals, to develop a clinical test battery in order to be able to describe the auditory problems of each elderly individual, and to develop better hearing aids and rehabilitative practices for elderly hearing-impaired listeners. Implied in the need to better understand the changes in auditory processing as a function of age is the importance of psychoacoustic and speech-perception research. The hearing problems of the elderly are complex, and it is only through rigorous research that an understanding of hearing in aging listeners can be reached.

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