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Auditory Temporal Processing in Elderly Listeners

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Abstract

This paper examines the hypothesis that auditory temporal processing is impaired in elderly listeners. Several recent psychoacoustic studies are reviewed that describe various aspects of temporal processing that appear to be influenced by aging. The temporal phenomena range from measures of temporal resolution and duration discrimination to sequential processing of complex stimulus patterns. For many of the research findings, age-related deficits on temporal performance measures are unaffected by the presence of presbyacusic hearing loss. Additionally, the consequences of aging on auditory temporal processing appear to be correlated with the complexity of stimulation and the difficulty of the listening tasks.

Key Words: Age effects, hearing loss, presbyacusis, sequential interference, temporal processing

Historically, the study of hearing and aging has focused on problems of speech perception and comprehension experienced by elderly persons. Sources of the age-related perceptual difficulties are varied and poorly understood (CHABA, 1988). Nevertheless, examination of the research literature indicates that an important component of speech recognition problems could be related to underlying deficits in the auditory temporal processing abilities of elderly listeners. This possibility is suggested from results of several studies that used various forms of temporally degraded speech signals (e.g., time compressed, reverberated, periodically interrupted) to demonstrate perceptual difficulties that were unique to elderly listeners (Sticht and Gray, 1969; Korsan-Bengsten, 1973; Konkle et al, 1977; Harris and Reitz, 1985; Helfer and Wilber, 1990). Such age-related performance deficits with these degraded speech signals were thought to be associated with a gradual decline in time-dependent auditory processing abilities (Bergman, 1971). This early conclusion is also consistent with current views about cognitive processes and aging, which stipulate a generalized, age-related slowing of information processing that is observed to vary in degree with factors such as stimulus complexity and task difficulty (Salthouse, 1985; Wingfield et al, 1985; Cerella, 1991).

Despite the prevalence of studies on aging with complex temporally degraded speech, relatively little is known about the underlying temporal processing abilities of elderly listeners. Indeed, previous comprehensive reviews on aging and auditory processing served to highlight the general lack of available information about the psychoacoustic abilities of elderly listeners (Marshall, 1981; Olsho et al, 1985). The importance of psychoacoustic investigation lies in the capacity to examine specific aspects of auditory processing without the confounding influence of cognitive and semantic effects that are inherently involved in speech understanding. In recent years, several investigators have begun to use a variety of nonspeech stimuli in psychophysical tasks to examine different aspects of auditory temporal processing in elderly listeners. The following brief review of some recent psychoacoustic studies on aging examines performance measures that range in focus from estimates of auditory temporal sensitivity for simple sounds to temporal processing of complex sequential stimulus patterns. While the cumulative psychophysical evidence is still small, the recent findings indicate that many elderly

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listeners may have substantial limitations in temporal processing that become more evident as the level of stimulus complexity and demands of the listening task increase.

TEMPORAL SENSITIVITY: SIMPLE STIMULI

Psychophysical experiments on auditory temporal sensitivity usually aim to measure a listener's ability to detect or discriminate changes in the temporal properties of stimulation. Some of the recent studies on aging were designed to investigate auditory temporal resolution by measuring the ability of elderly listeners to detect rapid changes in the stimulus waveform. Other experiments focused on the capacity of listeners to discriminate small changes in the duration of a signal. Typically, the psychophysical tasks were conducted using forced-choice discrimination procedures in order to avoid potential confoundings related to age-related differences in listeners' response bias. Additionally, most of the psychophysical data are collected using suprathreshold stimulus levels in experiments that are designed to examine the independent effects of age and hearing loss on the temporal processing measures.

Temporal Resolution

Much of the available data on auditory temporal resolution comes from experiments on temporal gap detection. This procedure measures the ability of listeners to detect the presence of a brief temporal interval between successive signals, usually discrete noise or tone bursts. To date, the results of gap detection studies conducted with elderly listeners have produced equivocal findings. Moore et al (1992) used tonal signals and measured gap thresholds in groups of elderly subjects (ages 62–86 years) with and without hearing loss, and in a control group of young normal-hearing listeners. The average performance of the older listeners was poorer than that of the younger subjects, but this outcome was attributed to a small number of elderly listeners who exhibited quite poor resolution; the majority of elderly subjects had relatively normal gap thresholds that were largely independent of any effects of hearing loss. Similar conclusions were reported by Lutman (1991), who measured gap thresholds with noise signals and observed age-related resolution deficits for only a small percentage of the elderly listeners tested. However, more recent gap-detection results reported by Schneider et al (1994) indicate that age may have an important influence on temporal resolution. This study used pairs of brief tone pips at 2 kHz to measure gap thresholds in young (mean age: 23 years) and elderly (mean age: 69.2 years) listeners with normal hearing. Temporal resolution in most of the elderly listeners was about twice as poor as that of the younger subjects. Differences among these gap detection studies may reflect stimulus effects that can have an important influence on gap resolution in general, and perhaps age effects as well.

Another procedure for measuring temporal resolution was applied by Takahashi and Bacon (1992). This experiment tested the ability of young listeners with normal hearing and elderly listeners with near-normal hearing to detect periodic fluctuations in the envelope of a noise signal that was sinusoidally amplitude modulated at various rates. For this procedure, listeners with better temporal resolution are able to detect smaller degrees of amplitude modulation. The resolution performance of elderly listeners in three decade age groups (50s, 60s, and 70s) was compared to that of younger listeners (21–33 years). Generally, the elderly listeners were observed to be somewhat less sensitive to amplitude modulations than younger listeners, but no systematic effects of age emerged from the analyses of the results when the effects of hearing loss were taken into account.

Within the context of psychophysical models, temporal resolution estimates derived by gap detection and modulation detection are usually presumed to reflect limitations in sensory processing. To the extent that the models are valid, the collective resolution findings suggest that aging per se does not appear to cause consistent decrements in temporal acuity within the auditory periphery. This outcome, however, does not imply that all aspects of peripheral temporal processing remain unaffected by the aging process. For example, there is some evidence from pitch discrimination experiments (Moore and Peters, 1992) that may reflect dysfunctional peripheral coding of temporal information associated with the aging process. Also, it should be noted that sensorineural hearing loss is a well-documented consequence of aging (Corso, 1971; Pearson et al, 1995). As an independent factor, sensorineural hearing loss is known to influence several measures of auditory temporal resolution including gap detection (Irwin et al, 1981; Fitzgibbons and Wightman, 1982) and amplitude modulation (Bacon and Viemeister, 1985).

Duration Discrimination

Another fundamental aspect of auditory temporal processing references the capacity of listeners to distinguish changes in the duration of a stimulus event. The study of duration discrimination examines this temporal ability of listeners by measuring the difference limen (DL) for changes in stimulus duration. Presently, little information is available about duration processing in elderly listeners. One study by Abel et al (1990) measured duration DLs in young normal-hearing listeners (ages 20–35 years) and three groups of older listeners (ages 40–60 years) that differed by degree of hearing sensitivity ranging from normal hearing to moderately severe sensorineural hearing loss. The DLs were measured for reference stimulus durations of 20 msec and 200 msec using ⅓-octave noise signals at 70 dB SPL or greater in a forced-choice discrimination procedure. Despite their relatively young age, the older listeners exhibited generally poorer duration discrimination than the younger listeners, although performance variability was high. The degree of hearing loss among the older listeners had no discernible influence on discrimination performance.

A more recent investigation reports some clear age-related performance deficits in the processing of stimulus duration (Fitzgibbons and Gordon-Salant, 1994). The experiment measured duration DLs for tone bursts and for a silent interval bounded by tone bursts, with testing conducted at 500 Hz and 4000 Hz using 250 msec as the reference stimulus duration for all DL measurements. Testing was conducted on four groups of listeners: two groups of young subjects (20–40 years) with and without hearing impairment, and two groups of elderly subjects (65–76 years) with and without hearing impairment; the young and elderly listeners with hearing impairment had matched mild-to-moderate sloping sensorineural hearing losses. All testing was conducted at stimulus levels of 85 dB SPL. Results are displayed in Figure 1, which shows the mean duration DLs for the tones and silent intervals for each group of listeners. Analyses of these results revealed significant performance decrements among elderly listeners, with no effects of hearing loss, stimulus frequency, or reference stimulus (tone or silent interval).

The limited results available on duration discrimination indicate an age-related deficit in temporal processing that is largely independent of hearing loss. Theoretical modeling of duration

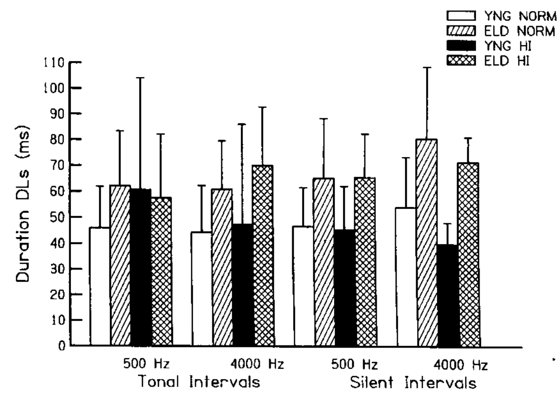

Figure 1 Mean duration difference limens (DLs) in msec for tonal and silent-interval signals in two frequency regions of young and elderly listeners with normal hearing and with hearing loss (from Fitzgibbons and Gordon-Salant, 1994).

processing has generally postulated that the perceptual coding of stimulus duration has a central auditory locus, with peripheral effects being influential only for brief stimulus durations (Creelman, 1962; Abel, 1972). Thus, some of the age effects observed on duration discrimination may reflect central auditory dysfunction in the elderly listeners. Presently, the restricted database and limited number of stimulus conditions make it difficult to draw conclusions about the locus of age-related dysfunction in the processing of sound duration.

TEMPORAL PROCESSING: COMPLEX STIMULI

Temporal discrimination performance that is measured with simple sounds presented in isolation gives an estimate of the listener's optimal capacity to resolve the details of stimulus properties. However, if the stimulation is more complex and comprised of multiple signal components, then discrimination performance can be influenced by a number of factors that are largely unrelated to inherent sensory capacities. For example, discrimination experiments conducted with complex sequential patterns demonstrate that cognitive and central "top-down" processing factors associated with listener uncertainty and familiarity with stimulus characteristics, as well as sequential interference effects and the information content of stimuli, can act to greatly diminish discrimination performance relative to that observed for simple sounds (Watson and Kelly, 1981; Watson and Foyle, 1985). Relatively few of these stimulus complexity effects have been studied with elderly listener populations, in which the potential for central auditory dysfunction might be expected to produce exaggerated temporal processing difficulties.

Discrimination of Tonal Sequences

Some examples of age-related difficulties associated with the processing of complex signals are available in the discrimination results reported by Humes and Christopherson (1991). This study compared the auditory skills of groups of "young-old" listeners (ages 65–75 years) and "old-old" listeners (ages 76–86 years) to those of groups of younger subjects (ages 19–36 years) who had normal hearing or noise-masked simulations of hearing loss similar in configuration and degree to sensorineural losses exhibited by the elderly subjects. The auditory performance of subjects was examined using a battery of discrimination tests (Test of Basic Auditory Capabilities, or TBAC) using both simple tonal stimuli and more complex sequences of tone bursts. Most of the significant age-related performance decrements observed in the study were found with the complex tonal patterns that measured temporal aspects of hearing, such as duration discrimination, perception of tonal rhythm, or the discrimination of temporal order. With the exception of frequency discrimination, age effects were less evident in performance measures collected with simple stimuli. Results of many tests also revealed that discrimination abilities among the oldest listeners tended to be more variable and generally poorer than those of the younger elderly listeners.

Results that provide an example of the magnitude of stimulus complexity effects on the temporal processing ability of elderly listeners come from a different study (Fitzgibbons and Gordon-Salant, 1995) that extended the earlier investigation of duration discrimination and aging cited above. Duration DLs were measured for an isolated tone (4 kHz, 250 msec) and for the same tone embedded within a sequence of five equal-duration tones that spanned a narrow high-frequency range. Additionally, separate complexity conditions were designed to vary the degree of listener uncertainty about stimulus characteristics. For example, one condition (Cond1) featured low uncertainty by presenting the same tonal stimulus pattern over a block of discrimination trials with the embedded 4-kHz target component always fixed in the middle sequence location. Two other conditions increased listener uncertainty by presenting different random tonal sequences on each discrimination trial, either with fixed target location (Cond2) or random target location (Cond3). The listeners in this experiment were comprised of four groups of young and elderly subjects with and without hearing losses, as described previously for the initial study.

Results of the discrimination experiments revealed large performance differences that were associated with the age of the listeners, with no significant influence of hearing loss. Figure 2 shows some of these results by displaying the mean duration DLs measured for the subject groups in each condition: the baseline condition (Base) for tones presented in isolation, and the three complexity conditions using tonal sequences as stimuli (Cond1, Cond2, and Cond3). Whereas the DLs of younger listeners showed little change across stimulus conditions, those of the elderly subjects exhibited substantial increases from baseline performance levels in each condition with the complex stimulus patterns. It is interesting to note that changes in the duration of an embedded sequence component, as implemented in these discrimination experiments, alters the perceptual rhythm of the tonal patterns. Thus, the age effects observed for duration discrimination with the tonal patterns may be a manifestation of age-related difficulty in the processing of temporal rhythmic structure, a result that is consistent with observations made by Humes and Christopherson (1991).

Sequential Interference

The discrimination experiments conducted with complex stimulus patterns demonstrate

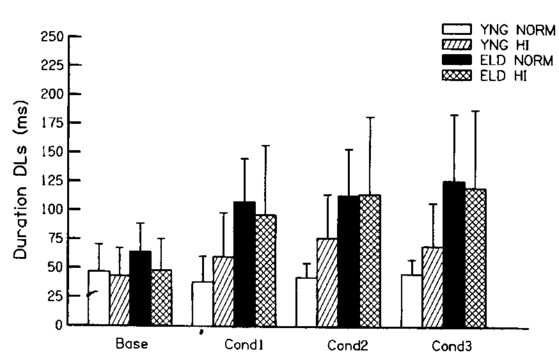

Figure 2 Mean duration difference limens (DLs) in msec of young and elderly listeners for tonal stimuli presented in isolation (Base) and in three complexity conditions (Cond1, Cond2, Cond3) with tonal sequences (adapted from Fitzgibbons and Gordon-Salant, 1995).

in a general way that stimuli presented in sequence can interact and interfere with discrimination processes. One psychophysical procedure that has been applied to examine the time course of sequential interference effects is the backward recognition-masking paradigm (Massaro, 1970, 1975). In this procedure, subjects are required to identify or discriminate properties of a target stimulus that precedes by varying time intervals a second signal of equal intensity that serves as a masker. Recognition performance of the target stimulus is generally found to be diminished for target-masker delays less than some critical interval, which is usually interpreted as the minimum processing time required for accurate target recognition.

Newman and Spitzer (1983) used the backward-recognition masking procedure to examine age-related performance differences in a pitch recognition task. Listeners were required to identify the pitch (high or low) of a brief 20-msec target tone (870 Hz or 720 Hz) that preceded a longer 500-msec masker tone (820 Hz) by an interstimulus interval (ISI) that ranged from 0 to 440 msec; all stimuli were presented at equivalent suprathreshold levels of 76-dB sensation level. Listeners included young (ages 20–29 years) and elderly (ages 75–85 years) subjects with normal or near-normal hearing in the stimulus frequency regions. Results of these measurements are displayed in Figure 3, which shows the percent correct target recognition as a function of the target-masker ISI in msec. The figure reveals that recognition performance of all subjects improved with an increase in ISI until an asymptote was reached

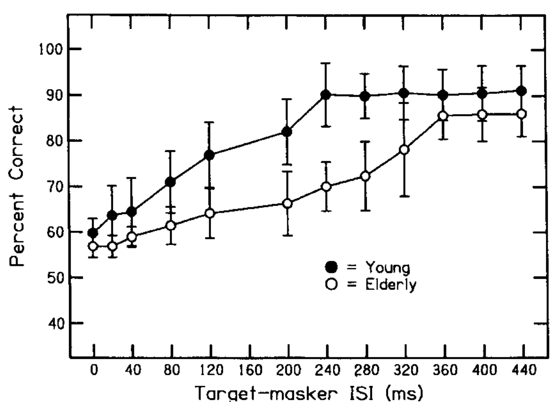

Figure 3 Percent correct target recognition as a function of the target-masker ISI in msec, by young and elderly listeners with normal or near-normal hearing (adapted from Newman and Spitzer, 1983).

at 248 msec for the young listeners and 360 msec for the elderly listeners; performance of the older subjects was generally poorer than that of the younger subjects for ISIs less than 360 msec. Newman and Spitzer (1983) interpreted these results as evidence for a longer processing time required by elderly listeners to achieve optimal recognition performance comparable to that of younger listeners.

Other results from backward-recognition masking experiments also show extended temporal interference effects among elderly listeners. Raz et al (1990) demonstrated age-related differences in backward interference for a frequency discrimination task but interpreted the results as reflecting age-related increases in sensory persistence (of the target stimulus), rather than slowed processing in aging auditory systems. This interpretation is consistent with results from other studies that hypothesize extended sensory persistence phenomena associated with aging (e.g., McCroskey and Kasten, 1982; Robin and Royer, 1989). At present, it is difficult to conclude with certainty about the nature of temporal processing mechanisms responsible for backward interference effects. It seems clear, however, that elderly listeners experience considerable difficulty in several of the sequential interference tasks.

Temporal Ordering

The capacity to perceive accurately the presentation order of sound elements is generally presumed to be an integral auditory ability required for processing complex forms of stimulation such as speech. The use of nonspeech signals to study temporal order perception provides a means of examining basic processing abilities independent of syntactic and semantic influences involved with speech processing. Nevertheless, even with unfamiliar sounds, numerous factors associated with stimulus type, number of stimuli in sequence, listener training, presentation rate, and response requirements can influence temporal order judgments. Additionally, the type of task, order discrimination versus order identification, is important, with discrimination generally being the easier task for listeners (Warren and Obusek, 1972; Divenyi and Hirsh, 1974; Nickerson and Freeman, 1974).

A study by Trainor and Trehub (1989) reported results for several temporal order experiments with tone sequences that compared the perceptual ordering abilities of young and elderly listeners. The ordering tasks involved both discrimination and identification, with the effects of presentation rate and listener training also examined. For all experiments, the poorest performance was exhibited by the elderly listeners (mean age: 70 years), a result that did not change across a range of stimulus presentation rates, or with increased practice. None of the results were correlated with the small differences in hearing sensitivity between young and elderly subjects who were tested. These results are consistent with other reports that also cite temporal ordering deficits among elderly listeners (e.g., Humes and Christopherson, 1991; Neils et al, 1991).

SUMMARY AND CONCLUSIONS

The studies reviewed here describe several aspects of auditory temporal processing and aging that were largely unexplored as recently as 5 years ago. Most of the investigations sought to describe suprathreshold performance measures that were independent of age-related sensorineural hearing loss. The research efforts revealed processing deficits on measures ranging from estimates of sensory temporal acuity to higher levels of information processing associated with sequential order perception. The evidence for age effects appears to be more consistent and robust for measures collected with complex stimuli in difficult listening tasks. This general trend suggests that age-related processing difficulties are predominantly a consequence of central auditory dysfunction, although the locus of processing disorders is difficult to determine from results collected with nonclinical populations of elderly listeners, as examined in most of the psychoacoustic studies. It is noteworthy also that many of the research findings reveal considerable variability in the processing abilities of elderly listeners.

Despite the progress made in defining some of the basic auditory processing skills of elderly persons, greater research effort is needed in several areas. In particular, the relevance of observed psychoacoustic deficits in temporal processing to the age-related problems in speech perception remains unclear. Some studies observed little relationship between basic psychoacoustic measures of temporal sensitivity and age-related deficits in speech recognition (e.g., van Rooij et al, 1989; Humes and Christopherson, 1991). Other findings indicate that duration discrimination abilities for simple sounds may be related to elderly listeners' recognition of reverberant speech (Gordon-Salant and Fitzgibbons, 1993). A clear understanding of these relationships is obscured by the complexity of processing resources, peripheral, central, and cognitive, that influence recognition and understanding of speech. However, it is encouraging to note that an increasing number of psychophysical studies use complex stimuli that more closely approximate the spectrotemporal characteristics of speech signals. Future studies with these complex forms of stimulation are likely to provide greater insight about the processing deficits underlying many of the speech understanding problems in the elderly listener.

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