Speech Perception and Auditory Temporal Processing Performance by Older Listeners: Implications for Real-World Communication

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ABSTRACT

This summary article commences with an overview of limitations in speech understanding of older listeners in challenging listening situations. Recent studies are reviewed that examine sources of the speech understanding problems of older listeners, including deficits in recognizing temporally altered speech. Corresponding data from psychophysical investigations of gap detection, duration discrimination, and identification of temporal order are considered in relation to the speech perception data. Evidence from numerous investigations indicates an age-related decline in auditory temporal processing that may contribute to the speech perception deficit. Moreover, tasks that increase the cognitive demand are also notably difficult for older listeners. Emerging techniques for applying recent findings of age-related speech and non–speech processing deficits are discussed, including developments in assessment, rehabilitation, and signal processing.

KEYWORDS: Aging, speech perception, temporal processing

Learning Outcomes: As a result of this activity, the participant will be able to (1) describe the types of speech recognition measures for which age-related deficits, independent of hearing loss, are likely to be revealed; and (2) list five distinct psychoacoustic measures that have shown substantial processing problems by elderly listeners.

Changing demographics in the United States indicate that the number of individuals older than 65 years with significant hearing loss will more than double in the next 15 years. Perhaps the most common complaint of this population is difficulty in understanding speech, particularly in challenging listening situations. One theory stipulates that the speech understanding problems of elderly people can be accounted for primarily by the loss of

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hearing sensitivity.[1] A contrasting theory suggests that other age-related changes, in addition to the loss of sensitivity, contribute to the older person's deficit.[2] Support for both theories can be found in the speech recognition literature, with findings of excessive age-related deficits highly dependent on stimulus complexity and listening task. The factors that underlie possible age effects on speech recognition tasks are likely to be related to alterations in auditory processing or cognitive decline, or both. This review article summarizes findings from recent speech perception and psychoacoustic investigations that underscore the range of deficits exhibited by older people. Emerging clinical techniques to address processing problems specific to aging are considered.

Recognition of undistorted speech materials presented in quiet listening conditions generally does not show a decline with age, when audibility is taken into account.[3] A specific age effect also may not be observed in noise, if word or sentence stimuli are highly audible or equally audible between age groups and the noise is presented at a favorable signal-to-noise ratio.[3,4] However, age-related differences may be observed in less favorable signal-to-noise ratios[5] or if speech recognition is assessed using an adaptive procedure.[6,7]

Older people do exhibit consistent speech recognition deficits, relative to younger listeners, when identifying stimuli that have been altered in the time domain. For example, older listeners have excessive difficulty recognizing time-compressed speech[8–10] and reverberant speech,[8] even when presented in quiet listening conditions. Another communication challenge facing older listeners is in understanding accented English, which typically features alterations in the duration of specific phonemes and in the overall timing structure of the spoken message. Elderly listeners show poorer recognition of English words and sentences spoken by native Taiwanese and Spanish speakers compared with young and middle-aged adults.[11] All of these findings tentatively support the idea that aging is accompanied by a slowing of auditory processing.

Cognitive changes also may occur with normal aging, including alterations in working memory, selective attention, and speed of information processing. Limitations in these abilities may also affect speech understanding. For example, lengthening the recall task by requiring listeners to identify sentences, rather than the final word of a sentence, is more difficult for older listeners than younger listeners.[12] In everyday group communication situations, the talker may change from moment to moment. Elderly normal-hearing and hearing-impaired listeners exhibit significantly poorer word recognition performance than younger listeners in conditions with multiple talkers compared with conditions with a single talker.[13] Thus, there appear to be age-related deficits in adjusting to variations in talker characteristics. Taken together, these studies provide evidence that alterations in more cognitive processes appear to influence speech understanding in elderly people.

Efforts have been made to unravel some of the basic auditory processing deficits that occur with aging and that may contribute to the observed speech recognition problems. Given that many of the speech understanding deficits of older people involve recognition of temporally altered speech, it seems reasonable to expect that problems in accurately perceiving temporal information in acoustic signals increase with age. Some psychoacoustic measures that mimic aspects of temporally altered speech include gap detection, duration discrimination, temporal order discrimination, temporal order recall, and tempo (or rhythm) discrimination. Performance on most of these measures is thought to be mediated by central auditory mechanisms.[14]

A basic measure of temporal acuity is gap detection, which assesses the smallest silent interval (gap) inserted within a continuous signal that a listener can detect. Young normal-hearing listeners exhibit gap detection thresholds of ~2.0 milliseconds[15] for gaps inserted in a continuous broadband noise. Age-related deficits have been observed on simple gap detection tasks,[16–18] but not consistently.[19] Decreasing the predictability of the location of the gap or increasing the complexity of the markers preceding and following the gap tends to show more consistent age effects.[19–21] In speech recognition, listeners are required to make judgments about the presence of a brief

silent interval (gap) to identify specific phonemes, such as the affricate /tʃ/, as in the word "ditch."

Older listeners show excessive difficulty in discriminating the duration of a tone compared with younger listeners.[20,22] These age effects are observed for isolated tones but are more prominent when the target tone is embedded in a sequence of tones.[22] Discrimination thresholds of young listeners are ~20% of the stimulus duration for isolated tones and target tones in a sequence, with reference tones of ~250 millisecond. However, discrimination thresholds of older listeners exceed 40% for the same tones when embedded in stimulus sequences. Discrimination of continuous stimuli in sequences is relevant to discriminating the duration of a vowel in a word; vowel duration serves as a cue to final consonant voicing as in "bat" versus "bad."

Perception of temporal order involves discriminating or recalling the order of different stimuli in a sequence as a function of the duration of the component stimuli in the sequence. Older listeners demonstrate quite poor discrimination of the order of three contiguous tones of varying pitch presented in a sequence, with discrimination thresholds four or five times larger than those observed for younger listeners.[23] Temporal order recall for three-tone sequences is also significantly poorer for older listeners than younger listeners, particularly at fast presentation rates where component tones are 100 milliseconds in duration. Poor temporal order recall at these fast rates may be considered the psychoacoustic analog of recognition of speech that has been time compressed to 50% of the original speech rate.

The ability to understand speech depends, in part, on the prosody, or overall timing, of the speech sequence. Findings from speech studies suggest that when the natural prosody is disrupted, older listeners have more difficulty accurately recalling the message than younger listeners.[23] The ability to discriminate the overall temporal patterning or rhythm of a sequence is called tempo discrimination. One way to manipulate the tempo of a sequence of tones is to vary the tonal interonset interval (IOI). Significant age effects are observed on tempo discrimination tasks for simple stimulus sequences involving tones of fixed frequency and duration, where the only change in the sequence pattern is an increment in the tonal IOI throughout the sequence.[24] In addition, older listeners show excessive deficits, relative to younger listeners, in discriminating sequence tempo for spectrally and temporally complex sequences.[25] However, the age-related deficits are significantly larger for the temporally complex conditions compared with the spectrally complex conditions. Effects of hearing loss are minimal in all of the temporal discrimination measures, including duration discrimination, tempo discrimination, and temporal order discrimination.

The findings of excessive age effects on temporally mediated speech recognition and psychoacoustic tasks have prompted the development of several diagnostic and rehabilitative techniques. The Gaps-in-Noise (GIN) test presents a series of broadband noise stimuli with gaps inserted at various locations to derive an estimate of gap threshold, in milliseconds.[26] Young listeners with normal hearing show average gap thresholds of 4.9 milliseconds on this task. Performance in the GIN test is affected by stimulus presentation level,[27] suggesting that standardization of the test for elderly listeners will need to account for age-related hearing loss in selecting presentation level. Interactive computer-based training software is also emerging, including the Listening and Communication Enhancement (LACE) program (www.neurotone.com) that includes presentation of degraded speech signals using an adaptive paradigm. A second training program, offered by Posit Science (www.positscience.com), applies principles of perceptual learning and brain plasticity to improve speech understanding and cognitive function. Signal processing strategies also are being developed to alter the temporal characteristics of specific speech signals so that the processed speech cues are within the temporal resolving capacity of older listeners.[28] Recent findings suggest that older listeners can benefit by ~25 to 30% from increments in the duration of consonants imposed on relatively fast speech, with less benefit observed for increments in vowel or pause duration.[28] All of these emerging techniques require systematic evaluation with a

suitable population of elderly individuals to determine the significance of performance improvements immediately following use as well as longitudinally. Nevertheless, these clinical applications hold considerable promise for benefiting older listeners in everyday listening situations, particularly because difficulty understanding degraded speech, with or without hearing aids, remains one of the largest complaints of senior citizens.

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ABBREVIATIONS

GIN	Gaps-in-Noise
IOI	interonset interval
LACE	Listening and Communication Enhancement

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