Auditory temporal processing and aging: implications for speech understanding of older people

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Introduction

Current estimates of the prevalence of age-related hearing loss among those over 65 years in the U.S. converge on an overall prevalence rate of approximately 50%, suggesting that there are currently 20 million senior citizens with significant hearing loss (Agrawal *et al*., 2008; Cruickshanks *et al*., 1998; Moscicki *et al*., 1985). Because the post-World War II baby generation (generally known as the *Baby Boomers*) is approaching retirement age (and hence known as the *Golden Boomers*), it is anticipated that the population of those over 65 years with age-related hearing loss will increase to 36 million by the year 2030. Perhaps the #1 communication challenge reported by older adults is difficulty understanding speech in less-than-ideal conditions. These conditions include poor acoustic environments (noise or reverberation) or speech that is produced by individuals with accents or fast speaking rates. The problems in speech understanding in demanding communication situations are reported by older people with hearing loss as well as those with normal hearing. One key challenge for researchers is to identify those aspects of the communication breakdown that are attributed to loss of hearing sensitivity vs. those that are associated with other factors that accompany aging.

A number of factors potentially contribute to the older listener's difficulty understanding speech in realistic listening conditions. The principal factor is associated with acquired changes in the peripheral auditory system, including loss of hair cells, tissue of the stria vascularis, and neural cells. In particular, loss of strial tissue appears to be a consequence of the aging process and results in a decrease in the endocochlear potential (Mills *et al*., 2006). A decrease in the EP affects the normal gain function provided by the cochlear amplifier and results in a loss of hearing sensitivity that is greater in the high frequencies than in the low frequencies. Loss of hearing sensitivity in the high frequencies directly reduces the audibility of weak, high frequency energy that is critical for conveying consonant cues, and, according to predictions of Articulation Index calculations, reduces speech recognition performance (ANSI, 1969). The age-related decline in the number and volume of spiral ganglion cells is associated with changes in the compound action potential with age, including an increased CAP threshold and decreased slope of input-output functions (Mills *et al*., 1990). These findings suggest that a loss of neural synchrony may result from the deterioration of neural units. Additionally, neural units of N. VIII code signal onsets and duration. Thus, age-related deterioration of neural cells likely affects the ability to code the onsets of signals and the successive onsets of a sequence of changing signals, such as occurs in speech.

There is also neural loss at every nucleus of the central auditory nervous system (CANS) with aging (Willott, 1991). Units in the CANS specifically code signal onsets, duration, and offsets; hence, age-related changes in the CANS further implicate reduced coding of incoming temporal information in signals, leading to distorted perception and slowed neural processing. Additional age-related changes that occur in the CANS relate to reduced inhibitory mechanisms. Caspary and his colleagues (1995, 2005) have observed increases in spontaneous firing and maximum firing rates, and decreases in nonmonotonic rate-level functions in the IC and AI in aging Fischer 344 rats. These types of changes appear to be related to an age-related decrease in inhibitory neurotransmitter function, including decreases in glycine receptors in dorsal cochlear nucleus (DCN), in the inhibitory neurotransmitter γ-Aminobutyric acid (GABA) in inferior colliculus (IC), and in glutamic acid decarboxylase (GAD) throughout primary auditory cortex (AI). These neurochemical changes may limit the ability of the older listener to code signals accurately or suppress irrelevant information.

Cognitive factors are also believed to limit the older listener's ability to understand speech in challenging listening situations. For example, as people age, their working memory capacity may decline (Stine & Wingfield, 1987). This is manifested as difficulty in holding information in a temporary storage while processing its meaning or while waiting for additional information. Selective attention, or the ability to focus on a primary signal and ignore irrelevant signals, also is known to decline with aging (Madden and Langley, 2003). The decline in selective attention may be related to problems in ignoring background noise or suppressing relatively unimportant variations in a spoken message. A third cognitive ability of relevance to speech understanding is speed of information processing. Numerous studies have shown that on a wide range of psychophysical tasks, older listeners are not as able as younger listeners to process information accurately when it is presented at a rapid rate (Salthouse, 1996; Wingfield *et al*., 1985). This may be one underlying reason for older listeners' difficulty following

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the speech of people who talk at fast rates.

The first goal of our research program is to examine the hypothesis that as people age, there is a decline in the ability to process temporal (timing) information, including isolated brief acoustic stimuli and sequences of stimuli presented at varying rates. The secondary goal is to identify the importance of these age-related changes in auditory temporal processing on the ability to understand speech in everyday, challenging communication situations. We believe that auditory temporal processing abilities are critical for understanding speech for a variety of reasons. First, listeners must process brief, time-varying acoustic information in speech to recognize individual phonemes (e.g., voice-onset-time, VOT, as a cue to initial voicing in plosives as in buy vs. pie). Second, listeners must process rapid acoustic information about individual phonemes in a sequence of changing acoustic cues. This requires the ability to process accurately the rapid onsets and offsets of brief signals. Third, listeners must follow the overall timing structure (prosody) of a spoken message. Studies have shown that prosody aids speech recognition (Wingfield *et al*., 1984), and it is possible that disruptions in prosody have a more detrimental effect on the speech recognition performance of older listeners compared to younger listeners.

The strategies that we use entail examining similar questions regarding age-related differences in auditory temporal processing using speech perception and psychoacoustic experiments, as each type of experimental paradigm has distinct advantages and disadvantages. The protocols also involve presenting simple stimuli in isolation to identify specific cues that may be difficult for older listeners, and to present these same stimuli in the context of more complex sequences to approach realistic stimuli encountered in daily communication. The experimental design involves comparing the performance of younger and older listeners with normal hearing and with hearing loss. Comparison of performance across these groups permits an assessment of the effects of hearing loss (e.g., older hearing-impaired vs. older normal-hearing listeners), as well as the effects of aging (e.g., older normal-hearing vs. younger normal-hearing listeners).

Psychoacoustic studies

A basic measure of auditory temporal resolution is gap detection. In the gap detection task, listeners are asked to detect the presence of a brief silent interval inserted in an otherwise continuous tone or noise burst. The shortest silent interval that a listener can detect is the gap detection threshold, in msec. Young listeners with normal hearing exhibit gap detection thresholds of about 2 msec (Plomp, 1964). While several studies have reported small age-related deficits in gap detection thresholds for silent gaps embedded in the center of a continuous signal (He *et al*., 1998; Schneider *et al*., 1994; Snell, 1997;), larger age-related differences in gap detection thresholds are observed for more complex stimuli, such as when the gap is located near the stimulus onset or offset (He *et al*., 1998) or when the components bordering the gap shift in spectral content (Fitzgibbons & Gordon-Salant, 1994).

The ability to judge the difference in duration between a reference signal and a comparison signal is called duration discrimination. One of our investigations examined whether older listeners have difficulty in discriminating stimulus duration for a pure tone and for a silent interval between two tones (Fitzgibbons & Gordon-Salant, 1995). In this experiment, the reference stimulus (tone or silent interval) was 250 ms, and listeners judged whether a comparison stimulus was longer. Separate conditions examined the difference limen (DL) for the target stimulus presented in isolation or embedded within a sequence of five components. Stimuli were presented at 85 dB SPL to be at least 25 -30 dB SL re: the pure tone detection threshold for hearing-impaired listeners. The results, shown in Figure 1, revealed that the older listeners exhibited longer duration discrimination DLs compared to the younger listeners for both tones and silent intervals (gaps) presented in isolation. However, the age-related differences were larger for target tones and gaps embedded in the complex sequence (Fitzgibbons & Gordon-Salant, 1995). Hearing loss effects were not observed on the duration discrimination task, for either simple, isolated stimuli or stimuli presented in the sequence.

The relatively large age-related differences on duration discrimination of a target component in a sequence led us to speculate that older listeners are less sensitive than younger listeners to an overall rhythmic pattern in a sequence. A subsequent study (Fitzgibbons and Gordon-Salant, 2001) examined listeners' ability to discriminate changes in sequence timing using isochronous sequences of five simple tone bursts. These tone bursts were each 4kHz in frequency, 50 ms in duration, and separated equally by silent intervals. They were presented at equal tonal inter-onset intervals (IOIs), defined as the time from the onset of one tone in the sequence to the time of the onset of the next tone in the sequence. In four separate conditions, the baseline IOIs were 100, 200, 400, and 600 ms, representing presentation rates ranging from relatively fast to relatively slow. In each listening trial, a reference tonal sequence was presented followed by two other sequences, one of which had all IOIs increased uniformly by increasing the silent intervals between the five tones. Listeners were asked to judge which one of the two comparison tonal sequences was different from the first (reference) sequence presented. The duration DL for increments of the tonal IOI was measured for each listener in each of the four rate conditions. Age effects were observed for all stimulus sequence conditions, with older listeners exhibiting IOI DLs that were about 2% larger than those of the younger listeners. However, the performance of all listeners was poorest at the fastest presentation rate (100 ms IOI) and stabilized at the longer sequence IOIs of 200-600 ms. Hearing loss effects were not observed in this experiment.

Because age-related differences were quite prominent at the fastest presentation rate, a follow-up study (Fitzgibbons, *et al*., 2007) examined interval discrimination with simple 2-tone sequences across a broader range of fast and slow rates. In this experiment, stimuli were pairs of successive 20-ms 4000 Hz tone pulses separated by a silent interval. The reference tonal IOIs were 25 through 600 ms. Results again revealed no hearing loss effects. However, age effects were observed across the range of reference IOIs, with the largest age-relat-

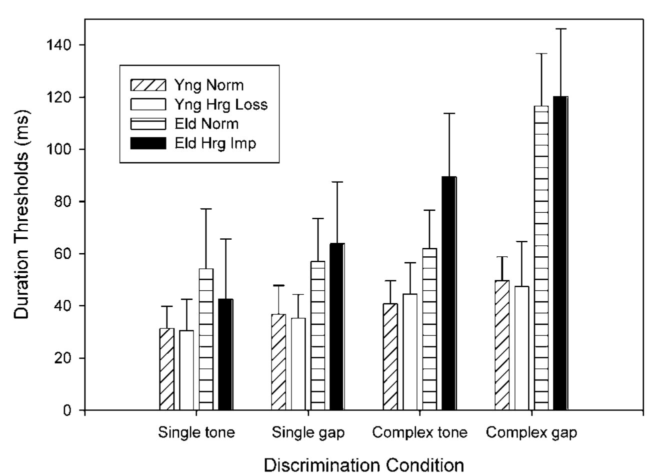

Figure 1. Duration discrimination thresholds (in ms) of four listener groups for single tones and gaps, and for the same tones and gaps embedded in a five-component (complex) sequence. (From Fitzgibbons & Gordon-Salant, 1995).

ed differences observed for the shorter reference IOIs (less than 100 ms), as seen in Figure 2.

One observation in these last two studies was that all listener groups exhibited small interval discrimination DLs for the sequences of tones comprised of five tones compared to the sequences comprised of two tones. This improved performance may have been attributed to the multiple presentations of the same tonal IOI within the longer 5-tone sequences. This possibility was examined directly in a study in which listeners judged differences in sequence IOI for isochronous sequences constructed of 2, 4, or 6 tones (corresponding to 1, 3, or 5 intervals), with each sequence presented at varying rates (25 ms, 50 ms, and 100 ms IOI). All tone bursts in the sequences were fixed at 4k- Hz and 20 ms. Listener groups were younger and older listeners with normal hearing, and older listeners with hearing loss. Results indicated that interval discrimination performance improved significantly in the 3-interval and 5-interval sequences compared to the single interval sequence, for all listener groups. Older listeners showed larger IOI DLs than younger listeners in all conditions, and the magnitude of this difference was significantly larger for the single-interval condition compared to the two multiple-interval sequence conditions. Performance was also better at the longest reference IOI (100 ms) compared to performance at the two shorter reference IOIs (25 ms and 50 ms) for all groups. These results indicate that listener sensitivity to changes in the duration of the tonal inter-onset intervals depends on listener age, the number of intervals within the sequences, and the magnitude of the intervals. While all listeners show improvement with multiple observations of a target interval, the older listeners appear to derive more benefit from these *multiple looks* than the younger listeners (Fitzgibbons & Gordon-Salant, 2011).

The final study of our series on discrimination of tonal sequences examined interval discrimination for an *accented* tone within a sequence, defined as a single elongated tone (Fitzgibbons & Gordon-Salant, 2010). This accented tone was designed as a correlate of accented phonemes in a spoken message in English, as produced by native speakers of Spanish. Stimulus sequences were constructed of six, 1k Hz tone pulses, with a reference tonal IOI of 200 ms, to approximate the duration of a sentence. In the baseline condition, all tone pulses were 50 ms. In the accented conditions, a single tone in the sequence was elongated by a factor of 2 (i.e., 100 ms in duration). In different accent conditions, the elongated tone pulse was located in the second, third, or fourth component position in the sequence. Duration DLs were measured for a single sequence target interval, occurring in interval 2, 3, or 4 in separate conditions. Results for the younger and older listeners are shown in Figure 3. The principal finding was a main effect of age in all conditions, in which older listeners showed larger DLs than younger listeners. Moreover, the magnitude of the age-related differences in discrimination performance was much larger in the accented sequence conditions than in the unaccented baseline condition.

In summary, older listeners exhibit larger difference limens than younger listeners on a range of duration discrimination measures including discrimination of simple, isolated stimuli and stimuli embedded within sequences. These findings indicate age-related differences in sensitivity to both localized and overall changes in timing. However, the results also show that older listeners benefit more than younger listeners by multiple observations of a target stimulus in a sequence. This suggests that short-term training with repetition of target signals may be useful for improving reception of brief cues in a sequence.

Speech perception studies

The principal goals of the speech studies are to examine the nature of age-related temporal processing deficits as they are manifested in perception of speech. Two levels of temporal processing in speech are examined: the first is processing the temporal fine structure in speech (i.e., brief temporal cues to phoneme identity) and the second is processing the amplitude fluctuations over the entire speech temporal waveform (e.g., speech presented at varying rates). These issues are investigated for variations in English spoken by native talkers as well for deviations in English as produced by native speakers of Spanish. Spanish-accented English was chosen for these investigations because this accent alters the duration of individual acoustic speech cues as well as the prosody of the spoken message, relative to native English.

The first set of experiments examined age-related effects in identification of contrasting word pairs that varied in a single temporal cue, for words presented in isolation and in a sentence context. The hypothesis was that age-related deficits for perception of target cues in speech continua would be more prominent in the sentence context than for

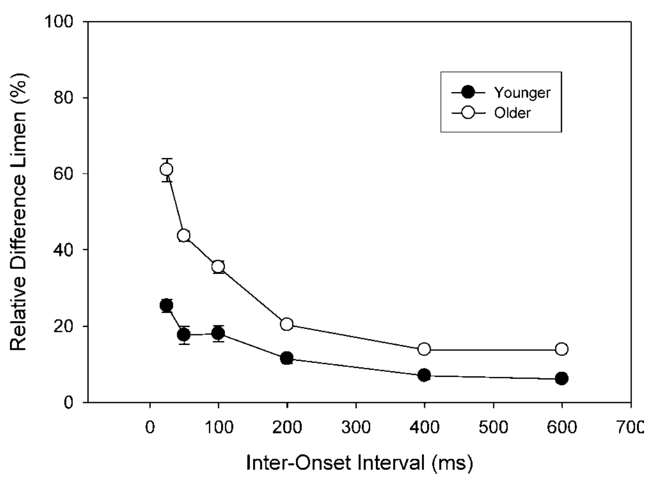

Figure 2. Relative DLs (%) for interval discrimination of younger and older listeners at six presentation rates. (From Fitzgibbons *et al.*, 2007).

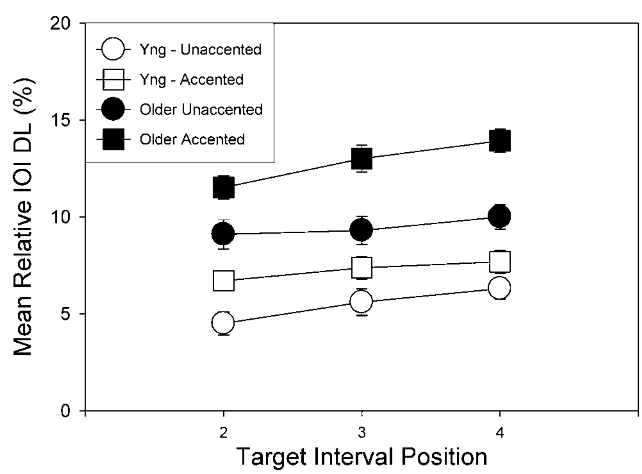

Figure 3. Mean relative IOI DLs (%) of younger and older listeners for isochronous tone sequences (*unaccented*) and tone sequences featuring a single elongated tone (*accented*), as a function of target interval position. (From Fitzgibbons & Gordon-Salant, 2010).

words presented in isolation, based on some of the psychoacoustic findings (e.g., Fitzgibbons & Gordon-Salant, 1995). Participants were younger and older listeners with normal hearing, older listeners with hearing loss, and younger noise-masked listeners. This last group included young listeners with normal hearing who were presented a low-level masking noise sufficient to shift their thresholds to be equivalent to those of the older normal-hearing listeners. The purpose of including the noise-masked group was to minimize the impact of subtle differences in hearing thresholds between the younger and older groups with normal hearing. The speech stimuli were recordings of low-context sentences in which the final word of each sentence was one of a pair of contrasting target words. Each pair of contrasting words was used to create a speech continuum of 7 equal-interval steps that varied in a single temporal cue. Four different speech continua were developed: voice-onset time (VOT, varying from 0 ms to 60 ms as a cue to buy vs. pie or Greg vs. Craig), silent interval duration (varying from 0 ms to 60 ms, as a cue to dish vs. ditch or Sue vs. Stew), glide duration (varying from 7 ms to 51 ms, as a cue to beat vs. wheat or Bill vs. Will), and vowel duration as a cue to post-vocalic voicing (ranging from 242 ms to 356 ms, as a cue to right vs. ride or Alissa vs. Aliza). Speech continua were created for words in isolation and words presented in sentences. On each listening trial, listeners heard a single word or single sentence and identified the target word from two choices. Percent identification performance for one of the two contrasting words was derived as a function of duration of the target cue. Individual crossover points were calculated from each listener's psychometric function. These reflect the duration of the target cue at which the listener's percept shifted from the word with the shorter cue (as in buy) to the longer cue (as in pie); i.e., the 50% identification point of buy. Effects of listener group and stimulus context (isolation, sentences) were examined separately for each continuum. These effects were significant for some, but not all, of the speech continua. Three patterns of group effects emerged. In one pattern, the older listeners required significantly longer target cues than younger listeners to shift their percept from the reference word (containing the shorter cue) to the contrasting word, for targets presented in sentences and in isolation (observed with the vowel duration cue, as in Alissa vs. Aliza). The second pattern, shown in Figure 4, also involved an age-related effect, in which older listeners required longer target cues than younger listeners to shift their percept, but this age effect was observed only for target words in sentences and not in isolation (observed with VOT, as in buy vs. pie). In the third pattern, both age and hearing loss effects emerged, with the older hearing impaired group requiring much longer target cues than the normal-hearing groups, and older normal-hearing listeners requiring longer target cues than the younger listeners, to shift their percept from the reference to the contrasting word (observed with the silent interval cue, as in dish vs. ditch). In all speech continua where age-related differences emerged, the older listeners required longer acoustic cues than younger listeners to alter their judgments about target word identity, suggesting that older listeners are less sensitive to brief temporal acoustic cues in speech (Gordon-Salant *et al*., 2006, 2008).

Perception of speech requires the ability to process variations in the rate of the spoken message. In some cases, talkers speak at a fast rate, and older listeners frequently report that it is difficult for them to understand the speech of such fast talkers. In an early experiment (Gordon-Salant & Fitzgibbons, 1993), we examined the effects of age and hearing loss on the ability to process speech presented at increasingly fast rates, using a simulation of fast speech called time compression. This simulation removes quasi-periodic portions of the temporal waveform, abuts the remaining portions of the signal, and applies a smoothing function at the junctions where the signal is concatenated. The time compression ratio, in percent, indicates the amount by which the original signal was reduced in duration. For example, an original signal that was 1000 ms and time-compressed by 60% would result in a signal that is 400 ms duration. The speech stimuli were low-context sentences that were presented in quiet at the uncompressed (original) rate, and time-compressed by 30, 40, 50, and 60%. Listener groups included younger and older listeners with normal hearing and younger and older listeners with matched, mild-to-moderate, gradually sloping sensorineural hearing losses. Significant main effects of age, hearing loss, and time compression ratio were observed, and there were no significant interactions. These findings indicate that older listeners experience considerable difficulty understanding speech presented at faster-than-normal rates, independent of the effects of hearing loss. These results also suggest that older listeners with hearing loss are at a considerable disadvantage for understanding rapid speech, because the effects of hearing loss and age operate independently, and therefore may become additive.

A follow-up study (Gordon-Salant, *et al*., 2004) investigated the hypothesis that older listeners experience more difficulty than younger listeners in adjusting to variations in speaking rate within a sentence. In this study, sentence-length materials were presented in one of six time compression conditions: uncompressed, uniform time compression in which the entire sentence was time compressed by 50%, and time compression (50% rate) of a single phrase in the sentence which could be the first, second or third phrase or a random phrase. Four listener groups (younger and older normal hearing, younger and older hearing-impaired) participated. Main effects of hearing loss, age, and time compression condition, as well as an interaction between age and

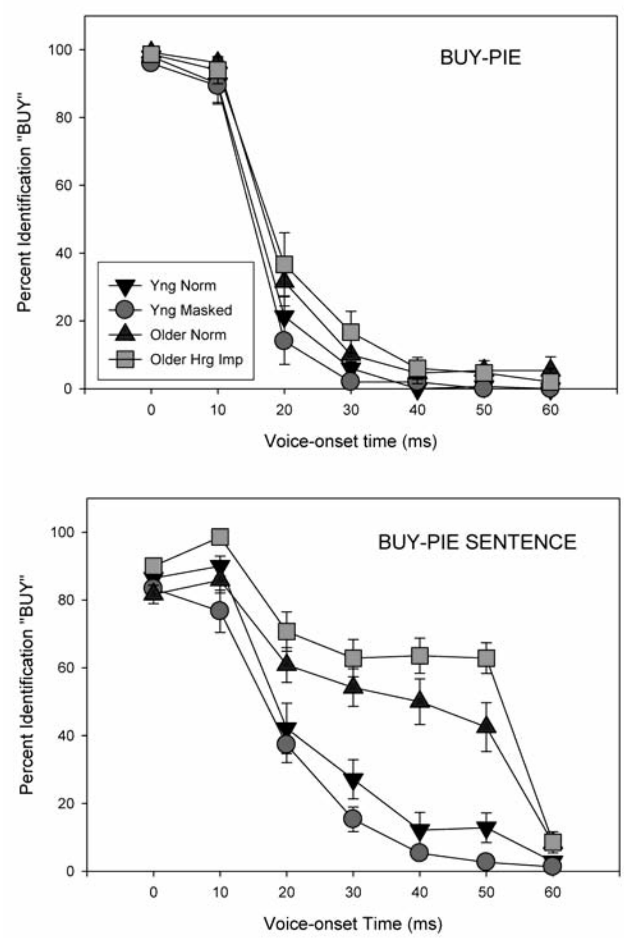

Figure 4. Percent identification of *buy* as a function of voice-onset time by four listener groups for words in isolation and in a sentence context. (From Gordon-Salant *et al.*, 2008).

time compression condition were observed. Older listeners performed more poorly than the younger listeners in all time compression conditions, but not in the uncompressed condition. Although age-related performance differences were observed in all time compression conditions, this difference was larger for the uniform time-compressed condition than for the single-phrase time compression conditions. Younger listeners showed poorer performance in the uniform time-compression condition compared to the uncompressed condition, but older listeners showed poorer performance for the single-phrase time compression conditions compared to the uncompressed condition, and poorest performance for the uniform time-compressed condition compared to all other conditions. This pattern of results suggests that older listeners are at a significant disadvantage relative to younger adults for understanding speech when even a single phrase in the message is spoken at a fast rate.

The observation of an age-related difference in recognition of time-compressed speech has been reported by numerous investigators (e.g., Wingfield *et al*., 1985; Vaughan & Letowski, 1997) and is one manifestation of the older listeners' difficulty in processing speech with altered temporal waveforms. One question that arises is whether this difficulty in understanding rapid speech is an inevitable consequence of the aging process. To investigate this question, we tested younger and older normal-hearing sighted listeners and older totally blind listeners

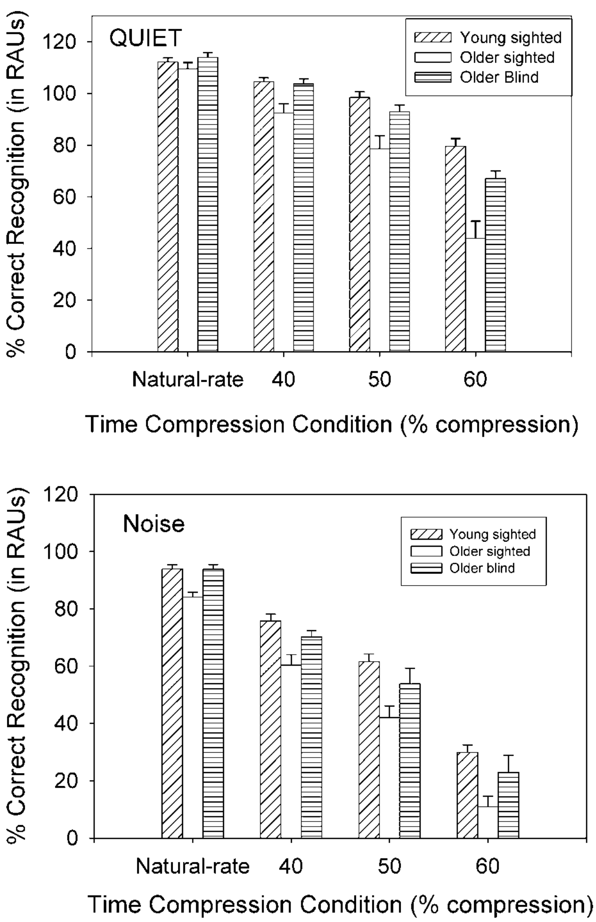

Figure 5. Percent correct recognition (in RAUs) at four time-compression conditions (0, 40, 50, 60% time compression) in quiet (top) and noise (bottom) by younger and older normal-hearing sighted participants and older normal-hearing blind participants. (From Gordon-Salant & Friedman, 2011).

with normal hearing (Gordon-Salant & Friedman, 2011). Because blind listeners rely on their auditory skills to adapt to the absence of visual information, it is possible that they may have retained the ability to process rapid speech with a high degree of accuracy. The speech stimuli in this experiment were the same low-context sentences used previously. They were presented to listeners in uncompressed form and at 40%, 50%, and 60% time compression ratios, both in quiet and in noise (signal-to-noise ratio, SNR = +7 dB). The results are shown in Figure 5. Significant main effects of group, noise, and time compression condition were observed, as well as significant interactions between group x time compression condition and between group x time compression condition x noise. Post-hoc analyses demonstrated that there were no performance differences between the three groups in the quiet, uncompressed condition. However, older blind participants performed significantly better than the older sighted participants in all time compression conditions in quiet and in the uncompressed and 40% time-compressed condition in noise. There were no performance differences between the older blind participants and the younger sighted participants in any condition. A correlation analysis was performed between performance in the most degraded time compression conditions (60% time compression in quiet and in noise) with number of hours the blind participants reported listening to speech materials recorded at faster-than-normal rates (e.g., books on tape). The r values were .82 and .88 for time-compressed speech in quiet and in noise, respectively. These findings indicate that the difficulty older listeners experience in understanding rapid speech is not inherent to the aging process, but rather, can be ameliorated through training and experience with speech presented at faster-than-normal rates.

Older listeners also report difficulty understanding accented English in everyday communication situations. Accented English is characterized by numerous changes in the spectral, intensive, and duration cues relative to native English. In the U.S., the most common first language of the foreign born is Spanish, thus, we have chosen to study perception of Spanish-accented English by younger and older listeners. Previous investigations suggest that the most common alterations in English with Spanish accent involve temporal cues, including voice-onset time (Flege & Eefting, 1988), vowel duration (Fox *et al*., 1995), and silent intervals as a cue that distinguishes an affricate from a fricative (tsh vs. sh) (Shah, 2004). In addition to these discrete acoustic cues, there are changes to the overall prosody in accented English. Spanish is considered a syllable-timed language in which every syllable is perceived to occur at regular intervals, whereas English is considered a stress-timed language, with isochronous intervals between stressed syllables (Pike, 1945). Native speakers of Spanish who learn English as a second language usually retain the stress and timing patterns of their native Spanish when speaking English and therefore produce sentences with a different tempo than native English speakers. Thus, Spanish-accented English potentially incorporates changes to the timing structure and to the amplitude waveform of spoken English, and older listeners may perceive this altered temporal information differently than younger listeners.

The first study in our series (Gordon-Salant *et al*., 2010a) examined whether age and hearing acuity affect perception of accented English. Participants were young normal-hearing, young noise-masked, older normal hearing, and older hearing-impaired listeners (n=15/group). Stimuli were 160 words with consonant and vowel phonemes that are often mispronounced by Spanish-accented speakers. These English words were recorded in isolation and in a sentence context by three speakers: a native speaker of American English, a native Spanish speaker with a mild accent, and a native Spanish speaker with a moderate accent. These stimuli were presented to listeners in quiet. Acoustic analyses of the words generally showed that compared to the native English speaker, the accented speakers produced shorter vowels, longer voice-onset times for word-initial consonants, and shorter silent intervals in affricates. The performance data showed that all four groups recognized the accented speech more poorly than the native English, with poorest performance for the stimuli recorded by the moderately accented speaker. No differences in recognition were observed for words vs. sentences, suggesting that altered prosody with accented English did not affect intelligibility. The older hearing-impaired group generally performed more poorly than the three normal-hearing groups, indicating an effect of hearing loss rather than of age. All groups exhibited significant errors for initial and final consonants with accent. Voicing errors were observed for word-initial and word-final consonants, while manner errors (fricatives for affricatives) were observed for word-initial consonants only. These consonant confusions were consistent with the acoustic modifications observed in the accented English words. It is noteworthy that the normal-hearing listeners were able to resolve most of the intended words spoken with accent, but the older hearing-impaired listeners had considerable difficulty perceiving these temporally modified signals. A subsequent study (Gordon-Salant *et al*., 2010b) examined further the impact of accent on perception of words in sentences. Stimuli were sentences in which the final word was the target word. There were four speaker conditions: i) accented speaker, in which the sentence and target word were spoken by a moderately accented speaker; ii) native speaker, in which the sentence and target word were spoken by a native speaker of English; iii) hybrid accented_native speaker, in which the carrier sentence was spoken by the accented speaker and the target word was spoken by the native speaker of English; and iv) hybrid native_accented speaker, in which the carrier sentence was spoken by the native speaker and the target word was spoken by the accented speaker. Stimuli were presented in quiet and noise, and listeners were asked to identify the entire sentence. In separate conditions, listeners were asked to judge the degree of accentedness of the sentences presented in quiet. As shown in Figure 6, all listener groups exhibited better recognition scores for the native and hybrid accent_native speech compared to the accented and hybrid native_accented speech, indicating that the accent of the speaker of the target word was the most important factor affecting recognition performance. Older listeners recognized accented speech more poorly than younger listeners in quiet and noise. For the accentedness ratings, listeners rated the accented and hybrid accented_native speakers as more accented than the hybrid native_accented and native speakers. Thus, listeners judged the degree of accent on the basis of the speaker of the carrier sentence. An age effect was observed in the accentedness ratings: older listeners rated the accented speech as less accented than the younger listeners. Taken together, it appears that older listeners are less sensitive than younger listeners to the degree of accent of a talker even though they experience more difficulty understanding accented speech.

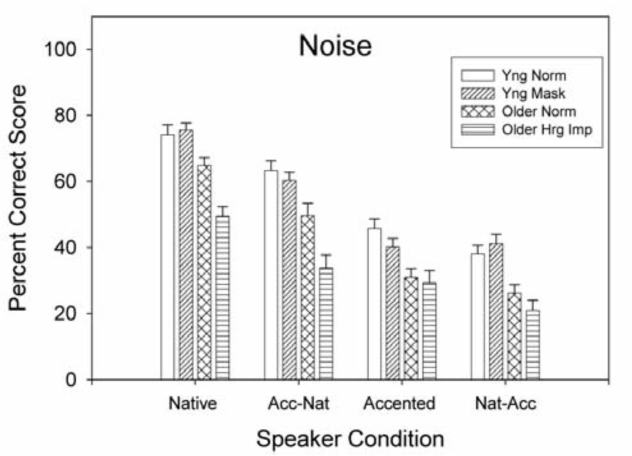

Figure 6. Percent correct recognition of unaccented and accented English in noise by younger and older listener groups. (From Gordon-Salant, *et al*., 2010b).

Summary

The psychoacoustic experiments show that older listeners have more difficulty than younger listeners judging changes in stimulus duration for simple tonal and gap stimuli. Moreover, these duration discrimination problems become even greater for complex stimuli in which the target component is embedded in a sequence of contiguous sounds. Age-related differences are also observed in the ability to judge sequence timing, either for uniform, isochronous sequences, or sequences that include an accented (elongated) tone. Although these age-related differences are seen across a range of presentation rates, they are much more prominent at faster presentation rates (<100 ms IOI) than at slower presentation rates. Nevertheless, it appears that older listeners are able to take advantage of temporal interval repetition in multi-tone sequences to improve their perception of sequence timing. The speech perception experiments examine age-related temporal processing deficits for brief, discrete acoustic cues to consonant identity as well as for alterations in speech rate. The converging evidence indicates that older listeners require longer cues for consonant identity than younger listeners, although this varies somewhat with the target cue and the context (isolated word vs. sentence). Older listeners also experience more difficulty understanding Spanish-accented English than younger listeners, which is likely attributed to a combination of altered temporal cues for consonant identity with accent coupled with the older listeners' reduced temporal processing abilities. Older listeners also exhibit considerable difficulty understanding speech presented at rapid rates, whether applied uniformly throughout a sentence or to a single phrase in a sentence. However, the performance of older normal-hearing blind listeners on rapid speech tasks is comparable to that of younger normal-hearing listeners, suggesting that training and experience should prove quite beneficial in improving perception of speech stimuli presented at rapid rates.

In conclusion, the speech and psychoacoustic results converge on the notion that older people experience deficits in auditory temporal processing that are manifested for simple, isolated stimuli as well as stimuli embedded in sequences. Age-related effects are most prominent for brief stimuli and stimulus sequences presented at fast rates. However, the results also suggest that older listeners may improve their auditory temporal processing capacity through repetition and practice at increasing presentation rates.

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