Selected Cognitive Factors and Speech Recognition Performance Among Young and Elderly Listeners

Sandra Gordon-Salant
University of Maryland at College Park

Peter J. Fitzgibbons
Gallaudet University
Washington, DC

The influence of selected cognitive factors on age-related changes in speech recognition was examined by measuring the effects of recall task, speech rate, and availability of contextual cues on recognition performance by young and elderly listeners. Stimuli were low and high context sentences from the R-SPIN test presented at normal and slowed speech rates in noise. Response modes were final word recall and sentence recall. The effects of hearing loss and age were examined by comparing performances of young and elderly listeners with normal hearing and young and elderly listeners with hearing loss. Listeners with hearing loss performed more poorly than listeners with normal hearing in nearly every condition. In addition, elderly listeners exhibited poorer performance than younger listeners on the sentence recall task, but not on the word recall task, indicating that added memory demands have a detrimental effect on elderly listeners' performance. Slowing of speech rate did not have a differential effect on performance of young and elderly listeners. All listeners performed well when stimulus contextual cues were available. Taken together, these results support the notion that the performance of elderly listeners with hearing loss is influenced by a combination of auditory processing factors, memory demands, and speech contextual information.

KEY WORDS: aging, speech recognition, cognitive factors, speech rate, working memory capacity

Cognitive abilities are inherently involved in speech processing. Several studies have suggested the relative importance of cognitive influences, in addition to auditory factors, that limit speech understanding among elderly people (e.g., Jerger, Jerger, Oliver, & Pirozzolo, 1989; van Rooij & Plomp, 1990). Other studies, however, indicate that the actual significance of cognitive components on the speech recognition performance of elderly listeners is minimal (Humes, 1996; Humes et al., 1994). These previous studies measured global neuropsychological indices of cognitive function, including intelligence scales and memory tests, from the elderly participants. The use of global measures of cognitive function, rather than discrete measures of cognitive skills that relate specifically to speech understanding ability, may be a source of the inconsistent findings regarding the relative importance of cognitive ability for understanding speech.

Two cognitive factors that decline with age may influence speech recognition performance. The first factor is working memory capacity, which refers to a temporary short-term store where information is held and related to later-occurring events. Cohen (1987) noted that working

memory capacity could affect speech understanding because parts of the spoken message must be kept in mind and related to later parts of the message for understanding logical relationships between words and concepts. The second factor concerns the rate of information processing, defined generally as the speed at which an individual can extract content and construct meaning from a rapid signal. Wingfield, Poon, Lombardi, and Lowe (1985) theorized that an age-related decline in processing speed would be particularly detrimental to the rapid decoding and construction of meaning required for online processing of fluent speech.

The impact of working memory capacity on speech understanding performance by elderly listeners has not been investigated extensively. Working memory, as examined on digit span tests, appears to decline minimally with aging (Gilbert, 1941). Age effects become prominent, however, on tasks requiring listeners to perform mental operations while retaining information in memory (e.g., Bromley, 1958; Craik, 1977). This kind of task may be analogous to sentence reception for syntactically or semantically anomolous sentences, in which an individual must store information presented early in the sentence and relate it to information presented later in the message. Recognition of speech in noise may also be viewed as a task that places demands on both working memory capacity and selective attention because the listener must focus attention on the target message and recall speech information in the memory store while ignoring irrelevant information.

The link between age-related limitations in working memory capacity, auditory function, and speech understanding among elderly listeners has been investigated by Pichora-Fuller, Schneider, and Daneman (1995). They presented sentences (with and without contextual cues) in noise to young and elderly listeners who recalled the final word of each sentence or the final words of the last *n* sentences in a set. Elderly listeners recognized speech more poorly than younger listeners in all conditions, but benefitted more from context than younger listeners. The introduction of a memory task did not influence word recall for either age group. Pichora-Fuller and her colleagues interpreted these results as supporting the notion that age-related differences in auditory processing, rather than working memory capacity, primarily influence speech understanding in noise.

Support for the notion that an age-related decline in processing speed affects speech recognition measures has been provided in a series of studies by Wingfield and his colleagues (for a review, see Wingfield, 1996). In one study, Wingfield et al. (1985) presented speech segments of varying word length, speech rate, and syntactic and semantic structure to young and elderly listeners with normal hearing. The performance of the elderly listeners declined more rapidly than that of the younger listeners with increasing speech rate and stimulus segment length, particularly for stimuli that lacked contextual information. Thus, limitations in speed of information processing among elderly listeners may be revealed with increments in speech rate.

Despite the evidence showing age-related processing difficulties with speeded speech, there is little empirical confirmation that elderly listeners' recognition performance could benefit from a slowing of presentation rate. Previous attempts to decrease speech rate for elderly listeners using mechanical time expansion techniques were generally unsuccessful (e.g., Korabic, Freeman, & Church, 1978; Luterman, Welsh, & Melrose, 1966; or see Willott, 1991, for a review). Several factors may have accounted for these findings. First, the mechanical time expansion method alters the spectral and temporal composition of the speech sounds and may have produced a distorted speech signal. Second, the speech stimuli were individual words, which are often recognized well by elderly listeners (Gordon-Salant, 1987; Willott, 1991). A better assessment of the possible benefits of slowed speech would use sentence stimuli and a time expansion method that retains the original acoustic characteristics of the spoken words. One potential method for slowing speech rate is suggested from studies investigating "clear speech," which refers to natural alterations in speech that occur when the speaker attempts to be more intelligible for listeners with hearing loss. A prominent acoustic characteristic of clear speech compared to conversational speech is a dramatic increase in both the number and duration of pauses between words (Picheny, Durlach, & Braida, 1986). The increased interword intervals of clear speech may provide additional processing time for the enhancement of sentence recognition performance. This hypothesis is examined in the present study.

This investigation assessed the effects of selected cognitive factors on the speech recognition performances of elderly listeners, as part of a large-scale study of temporal processing factors and age-related speech recognition deficits. Memory demands were investigated by comparing performance under conditions of final word recall and sentence recall. Although age-related effects are expected to be more evident under the increased processing and memory demands associated with a sentence understanding task (Cohen, 1987), direct comparisons between word and sentence processing by elderly listeners have not been reported previously. The influence of speed of information processing was assessed by altering the speech rate using increments in interword intervals (IWIs). We reasoned that slowing the rate of speech by increasing the silent intervals between words might be more beneficial to elderly listeners than to younger listeners because it provides more time for stimulus encoding. The role of peripheral processing

deficits was assessed by comparing performances of listeners with normal hearing to those with sensorineural hearing loss. Additionally, possible differential effects of the benefits derived from contextual cues by young and elderly listeners were examined with the use of stimuli that varied in the amount of semantic information. These comparisons permitted an assessment of three possible outcomes:

1. Elderly listeners' speech understanding is affected by limitations in memory capacity. If memory factors differentially affect young and elderly listeners, then a minimal age effect should be observed on a task that requires immediate recall of single words and a more sizeable age effect would be expected on a task that has an added memory load, such as sentence recall.

2. Elderly listeners' speech understanding is affected by limitations imposed by deterioration of peripheral auditory sensitivity. Support for an auditory processing deficit would derive from performance patterns in which listeners with hearing loss perform more poorly than listeners with normal hearing, regardless of age. This performance pattern would be evident particularly for low-context stimuli that require processing of the acoustic cues in speech for accurate recognition.

3. Elderly listeners' speech understanding is influenced by decreases in speech rate. If this were the case, then elderly listeners with and without hearing loss would derive greater benefit than younger listeners under conditions of slowed speech presentation rates.

It is also possible that multiple factors contribute to the performance patterns observed for elderly listeners. For example, elderly listeners with hearing loss may be limited by their peripheral hearing loss and decline in memory capacity. In this case, these listeners would exhibit poorer performance than that of listeners with normal hearing (both young and old) and younger listeners with hearing loss, particularly for low context stimuli and the sentence recall task.

Methods
Participants

Participants were assigned to one of the following four groups: (a) The young listeners with normal hearing group (YNH) included 10 individuals in the age range 18–40 years who had pure tone thresholds 15 dB HL (re: ANSI, 1989) from 250–4000 Hz; (b) the elderly listeners with normal hearing group (ENH) comprised 10 people, 65–76 years of age, with audiometric thresholds 15 dB HL from 250–4000 Hz; (c) the young listeners with hearing loss group (YHL) included 10 people in the same age range as the YNH group but who had gradually sloping, sensorineural hearing losses

of mild-to-moderate degree; and (d) the elderly listeners with hearing loss group (EHL) had the same audiometric characteristics as listeners in the YHL group but were within the same age range as listeners in the ENH group. Listeners in the two hearing loss groups were matched on a paired basis for audiometric thresholds between 250 and 4000 Hz. Means and standard deviations of the pure tone thresholds in the test ear for the four groups are shown in Table 1.

In addition to the age and hearing sensitivity characteristics, selection criteria for participants included monosyllabic word recognition scores (Northwestern University Auditory Test No. 6, NU6; Tillman & Carhart, 1966), obtained under earphones, of 80% or higher; tympanograms characterized by normal tympanometric pressure peak, tympanometric width, peak admittance, and equivalent volume (Shanks, Lilly, Margolis, Wiley, & Wilson, 1988); and a passing score on the Portable Mental Status Questionnaire (Pfeiffer, 1975), a screening test for cognitive function. Participants were also native speakers of English and possessed sufficient manual dexterity skills to provide a written response in a time-dependent manner.

The etiology of the hearing loss for the elderly listeners was presumed to be presbycusis on the basis of case history information, acoustic immittance measures, and audiometric characteristics. For the younger listeners with hearing loss, the etiology of the loss was heredity for 6 individuals and unknown for 4 individuals.

Stimuli and Noise

It was essential to use sentence-length material in order to examine the effects of manipulating speech

Table 1. Mean pure-tone thresholds (and standard deviations) in dB HL (re ANSI 1989) of the four groups (YNH = young listeners with normal hearing, ENH = elderly listeners with normal hearing, YHL = young listeners with hearing loss, EHL = elderly listeners with hearing loss).

	Participant group			
Frequency	**YNH**	**ENH**	**YHL**	**EHL**
250 Hz	3.9 (3.3)	11.0 (4.6)	21.0 (17.6)	20.0 (12.0)
500 Hz	2.2 (2.6)	8.5 (6.3)	20.5 (17.9)	21.0 (12.9)
1000 Hz	2.2 (2.6)	7.5 (6.3)	30.0 (21.3)	23.0 (10.0)
2000 Hz	0.0 (2.5)	8.0 (6.7)	39.5 (20.2)	33.0 (13.8)
4000 Hz	2.2 (2.6)	12.5 (4.9)	51.0 (14.7)	51.0 (8.4)

rate, length of the recall task, and availability of contextual cues. The basic speech materials were sentences from the Revised Speech Perception in Noise test (R-SPIN; Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984), including both low-predictability (LP) sentences that contain no semantic cues to the final test word of the sentence (e.g., "Mary had considered the *spray*") and high-predictability (HP) sentences that contain a controlled number of semantic contextual cues to final word identification (e.g., "Kill the bugs with this *spray*"). The eight forms of the R-SPIN sentences, each containing 25 LP and 25 HP sentences, were used in the study.

The noise background consisted of the 12-talker babble that is supplied with the R-SPIN sentences. The long-term spectrum of this noise resembles the long-term average speech spectrum (Kalikow, Stevens, & Elliott, 1977).

Computerized editing techniques were applied to create the experimental stimuli with selective increments in IWIs. The R-SPIN stimuli were played on a cassette tape recorder (Nakamichi Model 600), low-pass filtered at a nominal 5 kHz (Midnight Design Labs Signal Conditioning Unit) and digitized onto a laboratory computer at a 10 kHz sampling rate (Data Translation DT2801 analog-to-digital conversion board, Gateway 2000 486/33C computer). Waveform editing software provided a display of the waveform, which enabled visual identification of the boundaries between all contiguous words in each sentence. These boundaries subsequently were confirmed auditorily. Silent intervals were inserted at these word boundaries at the closest zero crossings to prevent audible clicks in the modified stimuli. Silent intervals of 400 ms, 800 ms, 1200 ms, and 1600 ms were inserted separately for each sentence. Pilot testing with a small sample of young listeners with normal hearing indicated that these modifications of speech rate were not detrimental to recognition performance. The digitized stimuli (modified and unmodified) were converted back into analog form at 10 kHz rate (Tucker-Davis Technologies DD1 array processor and signal processing board), low-pass filtered at 5 kHz, and recorded onto a digital audiotape recorder (SONY PCM 2500). The calibration tones provided at the beginning of each R-SPIN tape were similarly digitized onto the computer, converted back into analog form, and recorded at the beginning of each list of 50 sentences.

The unmodified and modified R-SPIN sentences were recorded onto Channel 1 of the DAT. A different randomization of the 50 sentences comprising each of the eight forms of the R-SPIN was recorded for each of the five IWIs (0, 400, 800, 1200, 1600 ms). The multitalker babble of the R-SPIN tapes was recorded

onto Channel 2 of the DAT directly from the audio cassette player. Two forms of the tapes were recorded to permit different response time intervals corresponding to the two recall tasks. The DATs prepared for the word recall task included an 8-s silent interval following each sentence, whereas the DATs prepared for the sentence recall task included a 16-s silent interval following each sentence. The final set of experimental DAT tapes consisted of 80 different versions of the R-SPIN sentence lists.

Procedures

Following preliminary test procedures (audiometric evaluation, acoustic immittance measures, screening for cognitive function), a brief practice session was conducted in order to familiarize each listener with the speech stimuli and the response tasks. Two samples of each of the five forms of sentence stimuli (5 IWIs) for both high and low-context stimuli were presented. Practice was given with each of the two response time intervals. The listener was asked to write either the last word of the sentence (final word recall) or the entire sentence (sentence recall). All listeners were able to provide the written response within the time allotted for each response task.

During the experimental sessions, the listener was seated in a double-walled sound attenuating chamber. The speech stimuli and background noise were played back from the DAT recorder/player on separate channels, amplified (Crown D-75), attenuated (Hewlett-Packard 350D), mixed and amplified (Colbourn audio-mixer amplifier S82-24), and delivered to a single insert earphone (Etymotic ER-3A). The test ear was the right ear for listeners with normal hearing and was the ear with better hearing sensitivity for listeners with hearing loss. The speech signal was presented at an overall level of 90 dB SPL, in order to approximate maximum performance of the listeners with hearing loss (Kamm, Morgan, & Dirks, 1983). The background noise was adjusted to a level of 74 dB SPL to create a S/N ratio of +16 dB. In preliminary testing, this combination of presentation level and S/N ratio produced an overall 70% correct recognition score for the LP-SPIN sentences by all listeners, a level of performance that was deemed desirable in order to prevent floor effects with the various stimulus and response manipulations incorporated in the present study.

The 10 experimental conditions (5 IWIs x 2 response tasks) were presented in random order. In addition, there was random assignment of R-SPIN list to condition. Preliminary testing and speech testing were completed in approximately 5 hours. Listeners were paid for their participation in the experiments.

Results

Recognition of Low-Predictability Sentences

Recognition scores for the LP-SPIN and HP-SPIN sentences were analyzed separately. Mean percent-correct scores of the four listener groups for the LP-SPIN sentences obtained with the word recall task are shown in the top panel of Figure 1. Individual percent-correct recognition scores were converted to arc-sine transformed scores and submitted for analysis of variance (ANOVA) using a split-plot factorial design (between-subjects factors were hearing status and age; the within-subjects factor was IWI). The statistical results for the word recall data are shown in Table 2 and indicate significant main effects of hearing status and IWI. The age effect and all interaction effects were not significant. Comparison of the mean scores for the two hearing loss groups indicate that listeners with hearing loss performed more poorly than listeners with normal hearing in all IWI conditions. Multiple comparison testing

(Student-Newman-Keuls procedure) reveals that listeners recognized final words in the 0 ms IWI condition (the baseline condition) better than in the 1200 and 1600 ms IWI conditions.

Percent-correct recognition scores for the sentence recall task were calculated by summing the total number of content words recalled correctly for a sentence list, dividing by the total number of content words for the list, and multiplying by 100. A content word was defined as any noun, pronoun, verb, adverb, adjective, or preposition (indefinite and definite articles were not considered to be content words). The percent correct scores obtained by the four listener groups for the sentence recall task are shown in the bottom panel of Figure 1. Arc-sine transformed scores were evaluated using ANOVA. The results, shown in Table 2, revealed significant effects of age, hearing status, and IWI. None of the interaction effects was significant. The effect of age was attributed to poorer performance by elderly listeners than by younger listeners in all conditions. In addition, listeners with hearing loss recognized the sentences more poorly than listeners with normal hearing.

Figure 1. Mean percent correct recognition scores for the LP-SPIN sentences obtained in the word recall task (top panel) and the sentence recall task (bottom panel) from the four listener groups (Young Normals = young listeners with normal hearing, Elderly Normals = elderly listeners with normal hearing, Young Hrg Loss = young listeners with hearing loss, Elderly Hrg Loss = elderly listeners with hearing loss).
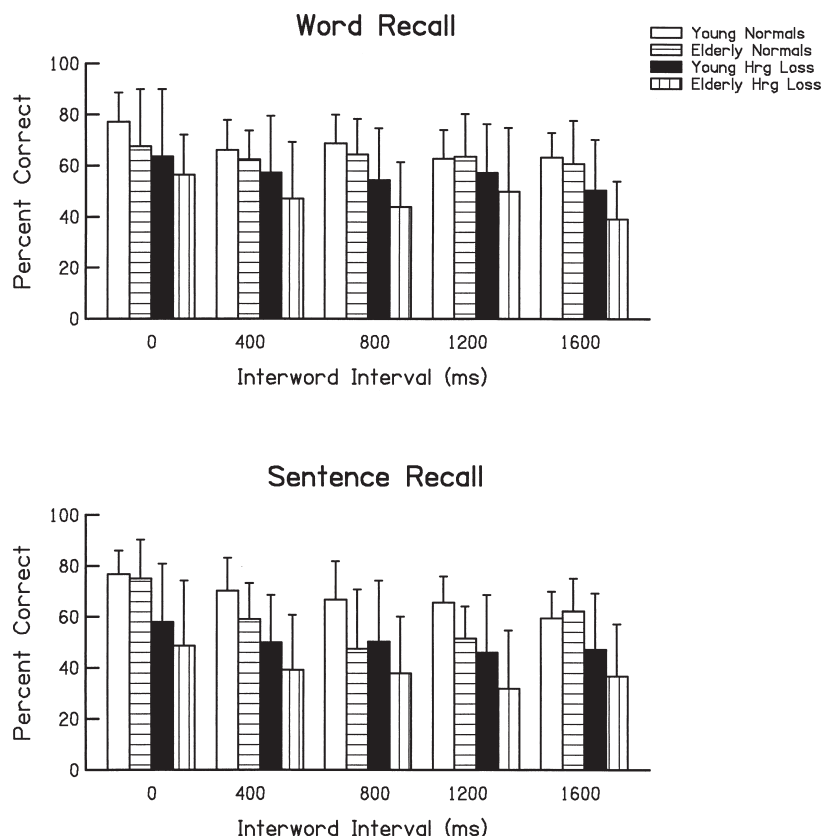
Table 2. F values for effects of Age, Hearing, and Interword Interval (IWI) for final word recall and sentence recall of Low-Predictability Speech Perception in Noise (LP-SPIN) sentences.

Source	df	Recall conditions	
		Word recall	Sentence recall
Age	1,36	2.29	4.50*
Hearing	1,36	8.58*	14.76*
Age x Hearing	1,36	.69	.13
IWI	4,144	5.33*	10.24*
Age x IWI	4,144	.41	1.98
Hearing x IWI	4,144	.48	.87
Age x Hearing x IWI	4,144	.47	.88

*$p < .01$

The effect of IWI was evaluated further using multiple comparison testing, which showed that listeners recognized sentences more poorly in the 400, 800, 1200, and 1600 ms IWI conditions compared to the 0 ms condition ($p < .05$). Listener performance did not vary across each of the incremented IWI conditions.

Recognition of HP-SPIN Sentences

Figure 2 presents the mean recognition performance data for the HP-SPIN sentences for word recall (top panel) and sentence recall (bottom panel). It is immediately apparent that many listeners achieved excellent recognition of the HP-SPIN sentences, particularly for word recall. The results of the ANOVA on the word recall data, shown in Table 3, indicate that the only significant effects were of hearing loss and IWI. Listeners with normal hearing performed better than listeners with hearing loss. Multiple comparison tests showed that all listeners exhibited better performance in the 0 ms IWI condition than the 1200 and 1600 ms IWI conditions ($p < .05$) and better performance in the 400 ms IWI condition than in the 1600 ms IWI condition ($p < .05$).

Analyses of the sentence recall data were performed and results are shown in Table 3. There were significant main effects of hearing status and IWI, and a significant interaction between these two effects. A simple main effects analysis of the hearing x IWI interaction revealed that the effect of hearing loss was not significant in the baseline (0 ms IWI) condition, but was significant at all

Figure 2. Mean percent correct recognition scores for the HP-SPIN sentences obtained in the word recall task (top panel) and the sentence recall task (bottom panel) from the four listener groups (Young Normals = young listeners with normal hearing, Elderly Normals = elderly listeners with normal hearing, Young Hrg Loss = young listeners with hearing loss, Elderly Hrg Loss = elderly listeners with hearing loss).
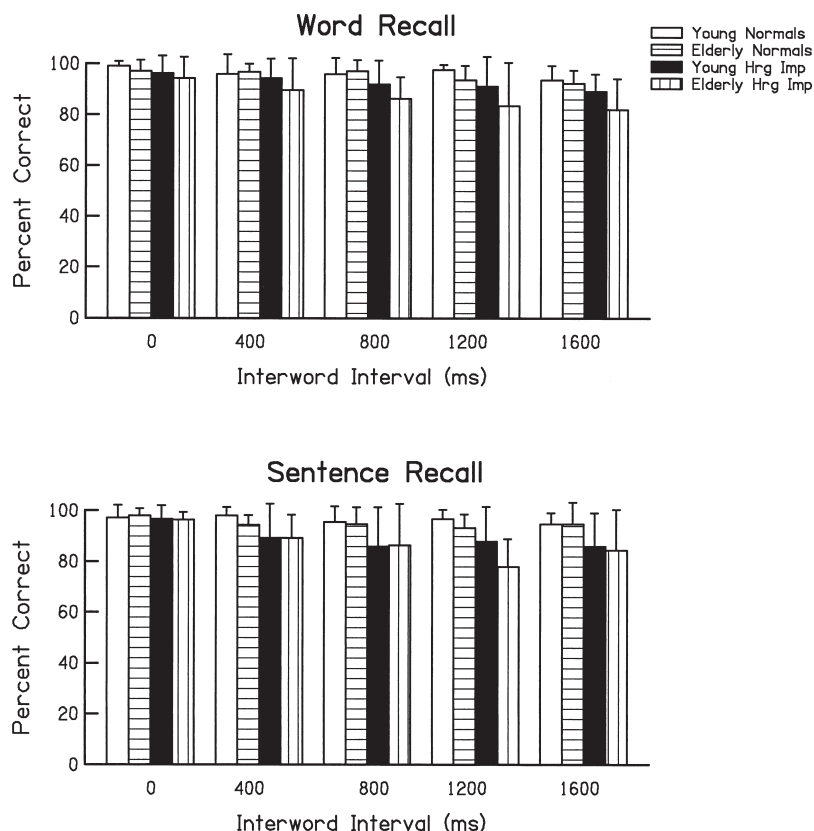
Table 3. F values for effects of Age, Hearing, and Interword Interval (IWI) for final word recall and sentence recall of High Predictability Speech Perception in Noise (HP-SPIN) sentences.

Source	df	Recall conditions	
		Word recall	Sentence recall
Age	1,36	3.05	1.60
Hearing	1,36	9.44*	10.14*
Age x Hearing	1,36	1.30	.04
IWI	4,144	9.51*	7.88*
Age x IWI	4,144	1.13	2.17
Hearing x IWI	4,144	1.81	2.63**
Age x Hearing x IWI	4,144	.42	.76

*$p < .01$
**$p < .05$

increased IWI conditions. These analyses also showed that the effect of IWI was not significant for listeners with normal hearing but was significant for listeners with hearing loss. Subsequent multiple comparison tests indicated further that listeners with hearing loss recognized the speech stimuli better in the 0 ms IWI condition than in the 1200 and 1600 ms IWI conditions ($p < .05$).

Discussion

The demands of increasing the memory load through alterations in the recall task appeared to have a differential effect on the performances of young and elderly listeners. Young and elderly listeners showed comparable word recall performance but elderly listeners recalled low-context sentences more poorly than younger listeners. These findings support the hypothesis that elderly listeners' speech understanding performance in noise can be affected by the added memory demands of a sentence recognition task. Whereas Pichora-Fuller et al. (1995) did not observe a strong influence of memory for word recall for either young or elderly listeners, the current results indicate that the added demands of memory may be particularly prominent for processing of sentences without contextual cues by elderly listeners. These observations suggest that the type of added memory demand may be an important variable that influences whether or not age-related performance differences are likely to be observed. The sentence recall task for low-context material may be viewed as placing similar demands on listeners as those that occur in some everyday conversational situations in which listeners must recall the speaker's entire message in order to respond appropriately. As shown here, these demands may place the elderly listener at a disadvantage compared to younger listeners.

Elderly listeners' speech understanding performance did not improve with slowing of the speech rate. Based on average recognition scores, an improvement in performance with increasing IWI was not observed in the recognition data for either low- or high-context sentences. This finding indicates that elderly listeners were not able to take advantage of longer processing time between words (silent intervals) to improve word encoding and to integrate sentence meaning. Despite the group effect, a few individual elderly listeners with hearing loss demonstrated improvement in sentence recall with the longest IWI, suggesting that speech slowing may be beneficial for selected elderly listeners.

All listener groups performed more poorly with increments in IWI compared to the baseline (0 ms IWI) condition in the sentence recall task for LP sentences. One interpretation of this finding is that inserting pauses between words disrupted the normal prosodic contour of the sentences, and effectively produced excised words from fluent speech that were presented within the context of a slower rate. According to Huggins (1972), prosodic cues are fundamental to speech perception in real-life communication. In the present study, inserting incremental pauses between words in the sentences may have altered phonemic clauses and natural boundaries that occur between words in a sentence or altered co-articulatory cues of contiguous words. The extent to which these prosodic and co-articulatory changes obscured any potential processing benefits associated with the slowing of the speech rate is uncertain. In addition, the uniform increments in interword intervals and the insertion of these increments between all contiguous words, incorporated in the present study, may not characterize the natural elongations within utterances that occur in clear speech. Thus, although the clear speech literature suggests that increasing the number and duration of pauses in a sentence may be beneficial, it is likely that the distribution and relative length of IWIs influence the magnitude of speech enhancement. Subsequent studies in the current research project on aging are designed to examine the effects of speech slowing by insertion of IWIs in a manner that preserves normal speech prosody.

Listeners with hearing loss performed more poorly than listeners with normal hearing in nearly every condition, despite the relatively high speech presentation level (90 dB SPL) and selection of listeners with good-to-excellent word recognition abilities. Unlike the age effect, the hearing loss effect was observed for both the word and sentence recall tasks, indicating that the principle limitation for these listeners was auditory processing of the acoustic characteristics of speech rather than memory processing. Taken together, the present findings indicate that the speech recognition performance of elderly listeners with hearing loss reflects a

combination of two factors: an auditory processing deficit associated with the loss of hearing sensitivity and a memory component associated with aging that is revealed on sentence-length tasks that place added demands on retaining information in the memory store. The performance patterns for elderly listeners with normal hearing suggest that these listeners are also affected by memory demands but not auditory processing limitations.

The availability of contextual cues had a dramatic effect on the performances of all listener groups. Examination of Figure 2 indicates that recognition of the HP sentences was consistently high (>80%), even among the elderly listeners with hearing loss. An age effect was not observed in the recognition data for HP sentences, although a hearing loss effect was apparent for some selected conditions. These findings are consistent with some earlier observations (Bilger et al., 1984; Pichora-Fuller et al., 1995; Stine & Wingfield, 1987; Wingfield et al., 1985) and indicate that despite depressed scores in the most difficult listening conditions, elderly listeners with hearing loss were able to take advantage of a few semantic cues to improve their recognition performance to nearly 100%. Thus, elderly listeners' knowledge of the language helps them to surmount the speech understanding difficulty imposed as a result of hearing loss, noise, memory demand, and disruptions in speech prosody such as those incorporated in the current experiment.

In conclusion, the elderly listeners in this study exhibited excessive deficits in recognizing sentences with minimal contextual cues, regardless of speech presentation rate. Hearing impairment imposed an additional deficit for speech recognition in noise. Slowing of speech rate with increments in IWI proved to be difficult for listeners in all groups, although several elderly listeners appeared to benefit from this type of temporal alteration. The principal finding, based on group performance patterns, was that the sentence recall task created an added memory load that affects speech recognition performance of elderly listeners. It appears, then, that age-related memory factors may influence speech understanding abilities of elderly listeners in difficult listening situations.

Acknowledgments

References

American National Standards Institute (1989). *American national standards specifications for audiometers*. (ANSI S3.6 - 1989). New York: ANSI.

Bilger, R. C., Nuetzel, J. M., Rabinowitz, W. M., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. *Journal of Speech and Hearing Research, 27*, 32–48.

Bromley, D. B. (1958). Some effects of age on short term learning and remembering. *Journal of Gerontology, 13*, 398–406.

Cohen, G. (1987). Speech comprehension in the elderly: The effects of cognitive changes. *British Journal of Audiology, 21*, 221–226.

Craik, F. I. M. (1977). Age differences in human memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 384–420). New York: Van Nostrand Reinhold.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. E. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). Plenum: New York.

Gilbert, J. G. (1941). Memory loss in senescence. *Journal of Abnormal Social Psychology, 36*, 73–86.

Gordon-Salant, S. (1987). Age-related differences in speech recognition performance as a function of test format and paradigm. *Ear and Hearing, 8*, 277–282.

Huggins, A. W. F. (1972). On the perception of temporal phenomena in speech. *Journal of the Acoustical Society of America, 51*, 1279–1290.

Humes, L. E. (1996). Speech understanding in the elderly. *Journal of the American Academy of Audiology, 7*, 161–167.

Humes, L. E., Watson, B. U., Christensen, L. A., Cokely, C. G., Halling, D. C., & Lee, L. (1994). Factors associated with individual differences in clinical measures of speech recognition among the elderly. *Journal of Speech and Hearing Research, 37*, 465–474.

Jerger, J., Jerger, S., Oliver, T., & Pirozzolo, F. (1989). Speech understanding in the elderly. *Ear and Hearing, 10*, 79–89.

Kalikow, D. N., Stevens, K. N., & Elliott, L. L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *Journal of the Acoustical Society of America, 61*, 1337–1351.

Kamm, C. A., Morgan, D. E., & Dirks, D. D. (1983). Accuracy of adaptive procedures estimates of PB-max level. *Journal of Speech and Hearing Disorders, 8*, 202–209.

Korabic, E. W., Freeman, B. A., & Church, G. T. (1978). Intelligibility of time-expanded speech with normally hearing and elderly subjects. *Audiology, 17*, 159–164.

Luterman, D. M., Welsh, O. L., & Melrose, J. (1966). Responses of aged males to time-altered speech stimuli. *Journal of Speech and Hearing Research, 9*, 226–230.

Pfeiffer, E. (1975). A short portable mental status questionnaire for assessment of organic brain deficit in elderly patients. *Journal of the American Geriatric Society, 23*, 433–441.

Picheny, M. A., Durlach, N. I., & Braida, L. D. (1986). Speaking clearly for the hard of hearing II: Acoustic characteristics of clear and conversational speech. *Journal*

of Speech and Hearing Research, 29, 434–446.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. *Journal of the Acoustical Society of America, 97*, 593–608.

Shanks, J. E., Lilly, D. J., Margolis, R. H., Wiley, T. L., & Wilson, R. H. (1988). Tympanometry. *Journal of Speech and Hearing Disorders, 53*, 354–377.

Stine, E. L., & Wingfield, A. (1987). Process and strategy in memory for speech among younger and older adults. *Psychology and Aging, 2*, 272–279.

Tillman, T., & Carhart, R. (1966). *An expanded test for speech discrimination utilizing CNC monosyllabic words*. Northwestern University Auditory Test No. 6. USAF School of Aerospace Medicine Technical Report. Brooks Air Force Base, Texas.

van Rooij, J. C. G. M., & Plomp, R. (1990). Auditive and cognitive factors in speech perception by elderly listeners.

II: Multivariate analyses. *Journal of the Acoustical Society of America, 88*, 2611–2644.

Willott, J. F. (1991). *Aging and the auditory system*. San Diego: Singular Publishing Group, Inc.

Wingfield, A. (1996). Cognitive factors in auditory performance: context, speed of processing, and constraints of memory. *Journal of the American Academy of Audiology, 7*, 175–182.

Wingfield, A., Poon, L. W., Lombardi, L., & Lowe, D. (1985). Speed of processing in normal aging: Effects of speech rate, linguistic structure, and processing time. *Journal of Gerontology, 40*, 579–585.