ADAPTATION to COMPRESSED SPEECH

in

YOUNGER and OLDER ADULT LISTENERS

by

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ABSTRACT

The present study investigated age differences in adaptation to compressed speech using a sentence recall task. Ten younger adults (aged 20-30 years) and 10 older adults (aged 62-78 years) were presented with 15 sentences at a naturally accelerated rate of 265 wpm (68% time compression), 15 sentences at a normal rate of 180 wpm, and then another 15 sentences at 265 wpm. Participants were instructed to listen to each sentence and recall it out loud as accurately as possible. Performance was evaluated in terms of the proportion of words correctly recalled. In view of known decrements in temporal processing, working memory capacity, and processing speed with age, older adults were expected to perform more poorly than younger adults at the accelerated speech rate. However, the results revealed no age differences in performance. Rather than impairing recall as predicted, moderate acceleration of speech rate had no effect on the performance of older participants and slightly enhanced that of younger participants. The results also offered preliminary evidence of adaptation to accelerated speech by a subgroup of younger and older participants who exhibited an improvement in recall performance over the course of 15-20 sentences. Furthermore, participants who demonstrated adaptation did not return to their original unadapted performance level after they were presented with uncompressed speech. This indicates that improvement in performance over the course of exposure to rapid input may reflect a learning process. Finally, it was hypothesized that the older group would adapt at a slower rate and to a lesser extent than the younger group due to age-related deficits in temporal/perceptual and cognitive processing. Although there were such age differences in the rate and degree of adjustment among participants who demonstrated adaptation, the effects were not statistically significant.

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1. CHAPTER ONE: INTRODUCTION

1.1 Introduction

Older adults often complain that they have difficulty understanding everyday conversation. The comprehension of spoken language is a complex task that involves not only the perception of the acoustic signal but also the integration of current and previously heard information with stored knowledge of the world, culminating in a meaningful interpretation of the intended message. Successful listening comprehension, then, requires general knowledge, intact auditory functioning, an ability to process information at a rapid speed, and a sufficient working memory capacity for simultaneous processing and storage of information.

Previous research shows that whereas linguistic and general world knowledge seem to remain relatively stable in later adulthood (e.g. Kemper, 1992), perceptual and cognitive processing appear to decline with age. Age-related deficits such as auditory temporal processing problems (Fitzgibbons & Gordon-Salant, 1996; Schneider & Pichora-Fuller, 2000; Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994), diminished speed of information processing (Birren, Woods, & Williams, 1980; Salthouse & Babcock, 1991; Verhaeghen & Salthouse, 1997) and reduced working memory capacity (Just & Carpenter, 1992; Light & Anderson, 1985; Norman, Kemper, & Kynette, 1992; Stine & Wingfield, 1987) may impair older adults' ability to process spoken language, especially when processing demands are high. Factors such as rapid speech (e.g. Stine, Wingfield, & Poon, 1986; Wingfield, Poon, Lombardi, & Lowe, 1985), the use of complex syntax (Kemper, 1986, 1997; Norman et al., 1992) and competing background noise (Pichora-Fuller, Schneider, & Daneman, 1995; Tun, 1998) exacerbate the demands of listening comprehension, thereby overburdening the limited capacity of older listeners.

Listening comprehension involves on-line analysis of acoustic information which is transient and rapidly changing. Unlike the reader who can set his or her own pace and backtrack whenever necessary, the listener must keep up with the rate of auditory input, which is under the direct control of the speaker. Conversational rates typically range between 140 and 180 wpm, although a TV or radio news broadcaster will often exceed 210 wpm (Stine, Wingfield, & Myers, 1990). The listener usually must rely on memory to retrieve information heard earlier. When the input rate is increased well beyond the normal range, comprehension by both younger and older listeners is impaired, but the performance of the latter group seems to be especially susceptible to fast input rates (e.g. Stine et al., 1986; Wingfield et al., 1985).

Previous research has shown that young listeners can learn to adapt to rapid speech through repeated exposure to it (Dupoux & Green, 1997; Mehler, Sebastian, Altmann, Dupoux, Christophe, & Pallier, 1993; Voor & Miller, 1965). Using a sentence recall task, Dupoux and Green (1997) found that adaptation to time-compressed speech occurs over the course of 10 to 15 sentences, with little improvement thereafter. They also found that sudden changes in talker and speech rate had minimal effects on the adaptation process. The present study was conducted to investigate whether older listeners demonstrate perceptual adaptation to fast speech and whether the adaptation process differs between younger and older age groups. The heavy demands of processing rapid speech may differentially impair older adults due to age-related deficits such as auditory temporal processing problems, a diminished working memory capacity, and/or cognitive slowing.

In the following section, empirical findings of an age-related decline in the comprehension of fast speech will be reviewed. Then previous research addressing each of the domains of auditory temporal processing, working memory, and cognitive slowing will be

discussed. This will be followed by a discussion of Dupoux and Green's (1997) study on the nature of adaptation to compressed speech and Hashtroudi, Chrosniak, and Schwartz's (1991) investigation of perceptual skill learning in older adults. Finally, the research hypotheses of the present study on age differences in adaptation to rapid speech will be outlined at the end of this chapter.

1.2 Literature Review

1.2.1 Age-Related Decline in the Comprehension of Compressed Speech

A number of researchers have found that an increased rate of speech input is particularly detrimental to the comprehension of older adults when compared to younger adults. For example, Wingfield and his colleagues demonstrated that older adults have more difficulty understanding and remembering speech when presentation rates are increased well beyond normal ranges (Stine & Wingfield, 1987; Stine et al., 1986; Wingfield et al., 1985; Wingfield & Stine, 1986; Wingfield, Tun, & Rosen, 1995). To increase the speech rate, the authors used time-compression, a method of artificially accelerating speech rate by digitizing recorded speech and periodically deleting small portions from the speech stream. The result is speech that is presented in a fraction of the original time while preserving most aspects of the intonation pattern of natural speech. When younger and older adults were asked to listen to sentences for later recall, all subjects tended to recall less material as the rate of speech was increased. However, relative to the performance of younger adults, the performance of older adults showed a disproportionate decline with an increase in speech rate. Moreover, this age-related deficit in the comprehension of time-compressed speech appears to be a phenomenon independent of audiometric hearing loss. Gordon-Salant & Fitzgibbons (1993) found that even older adults with normal hearing

thresholds show greater difficulty with time-compressed speech than normal-hearing younger adults.

Although the time-compression manipulation may remove "some of the natural redundancy inherent in the speech signal" or result in "a loss of signal richness" (Stine et al., 1986, p.306), older adults seem to respond to naturally spoken rapid speech in a similar way to artificially accelerated speech of equivalent speech rates (Schmitt & Carroll, 1985). One method of time-compression is to delete steady-state portions of the signal and leave the transient portions largely untouched, an approach which attempts to mimic the effects of rate changes in naturally spoken speech (Schneider & Pichora-Fuller, 2000). An age-related deficit in the comprehension of fast speech has been demonstrated using natural rate alteration (Schmitt, 1983; Schmitt & Carroll, 1985; Schmitt & Moore, 1989). These findings seem to mirror the real-world self-report of older adults that they sometimes have difficulty following rapid speech.

Not surprisingly, it has been suggested that comprehension by older listeners may be enhanced by slowing the rate of speech. In fact, a reduction in speech rate is one characteristic of elderspeak, a simplified speech register presumed to minimize processing demands and improve communication with older adults. Kemper (1994) found that both service providers (who work with healthy older adults) and caregivers (who work with frail older adults) used shorter, simpler sentences, spoke more slowly and paused longer when addressing either healthy or dementing older listeners. Although the use of slow speech is perceived as beneficial by conversational partners of older adults, empirical findings indicate otherwise. For example, Kemper and Harden (1999) found that while syntactic simplifications and semantic elaborations benefit older listeners' comprehension, and they are perceived positively, the use of a slow speech rate does not enhance their performance on a referential communication task, and it is perceived as

patronizing. Likewise, the results of studies involving both electronically and naturally altered speech rates indicate that slower-than-normal rates (less than 180 wpm) do not reliably facilitate comprehension for older listeners (Schmitt, 1983; Schmitt & Carroll, 1985; Schmitt & Moore, 1989).

An alternative approach to providing more processing time was recently investigated by Wingfield, Tun, Koh, & Rosen (1999). Instead of reducing the overall rate of speech, they restored artificially accelerated input to its original uncompressed duration by inserting pauses at clause and sentence boundaries. Hence, the speech signal remained compressed to the same degree but the insertion of pauses allowed more time for subjects to process the rapid input. The results showed that time-restoration helped subjects in both age groups to improve their recall performance. However, at the fastest speech rate of 300 wpm, when additional processing time was inserted into the stimuli, older listeners were not able to recover to the same performance level as that for uncompressed speech. This suggests that time-compression alters the perceptual input in a way which prevents older adults from processing it effectively, regardless of the amount of processing time available. It is possible that age-related deficits in lower-level auditory processing may make older listeners more susceptible to the perceptual stress of processing compressed speech, thereby limiting the degree to which they could benefit from additional time for higher-level processing. Wingfield et al. (1999) noted that, "...additional processing time in the form of pauses may be helpful only if the listener has processed enough material to serve as an adequate basis for integration." (p.18). All of these findings indicate that older listeners are differentially impaired by fast presentation rates in the comprehension of spoken language. In the following sections, several hypotheses are reviewed which posit possible explanations for the age-related decline in the comprehension of rapid speech.

1.2.2 The Information-Degradation Hypothesis

Schneider and Pichora-Fuller (2000) argue that in order to understand age-related changes in perceptual and cognitive functions, they must be viewed as part of an integrated system. In their integrated model, perception and cognition are highly interconnected and may share processing resources. The strong interaction between perception and cognition is evident in the fact that when the perceptual system delivers degraded information (e.g., fast speech, noisy signal) to the cognitive system, there is a decline in cognitive performance.

In a study involving word recognition in noise, Pichora-Fuller et al. (1995) examined the effects of processing difficulties at the perceptual level on higher-level processing. They proposed that in difficult listening conditions, a greater portion of the limited pool of processing resources are allocated to perceptual processing, thereby reducing the amount of resources available for linguistic and cognitive processing. In their study, young normal-hearing adults and older adults with near-normal hearing listened to sets of sentences with multi-talker babble background noise. Participants were required to perform two tasks. In the word recognition task, they were asked to repeat the sentence-final word. After listening to and identifying each sentence-final word in a set of sentences, they were asked to recall these words as part of the working memory span task. The results showed that older participants recalled fewer words heard in noise than younger participants, whereas there was no difference in recall performance when sentences had been read. This suggests that, in situations with competing background noise, the task of speech perception may consume more resources in older listeners than younger listeners due to age-related deficits in auditory processing. Hence, for older adults, more

resources may be drawn away from storage of information in working memory and other cognitive processes required for successful listening comprehension.

Tun (1998) also examined the effect of age on speech understanding in less than optimal listening conditions. She found that older listeners were less capable than younger adults at repeating sentences heard in noise and that this age difference in performance was even greater at faster speech rates. Thus, like background noise, acceleration of input rate seems to increase processing demands at the perceptual level and has a deleterious effect on performance, particularly for older adults.

1.2.3 Auditory Temporal Processing Deficits

Compression of the speech signal results in alterations of temporal acoustic cues (e.g., VOT, transition duration) and reduces them to extremely brief durations which are likely to be difficult for the perceptual system to interpret. In addition, the temporal relationship between these low-level acoustic cues may become distorted. Such distortion of the signal may create added perceptual stress for older listeners who have been shown to have deficits in auditory temporal processing (Fitzgibbons & Gordon-Salant, 1996). Schneider et al. (1994) found an age-related reduction in temporal resolving ability based on performance on the gap detection test. Gap detection is one of the most common ways of examining auditory temporal resolution and is a measure of the shortest silent interval or gap that can be detected between successive signals. In the Schneider et al. (1994) study, gap detection thresholds were determined by having younger and older listeners discriminate a gap between two tone pips from a brief continuous tone of equivalent total duration and energy. Older listeners' thresholds were found to be about twice as large as that of younger listeners, which suggests an age-related decline in temporal acuity.

Gordon-Salant and Fitzgibbons (1993) examined the effect of age on speech recognition with stimuli containing various forms of temporal speech distortion. In their study, younger and older listeners were asked to identify sentence-final words with sentences presented in three types of temporal distortion: time-compression, reverberation, and interruption. In addition to this word recognition task, temporal acuity was measured using the gap detection task, duration discrimination and a gap duration discrimination task. The latter two tasks measure the smallest increase in the duration of a tone or a gap that can just be detected. Older listeners were found to be poorer at recognizing all three forms of temporally distorted input. Results also showed that increased gap duration discrimination thresholds (reflecting poorer temporal acuity) were associated with reduced reverberant speech scores. Gap duration discrimination may be comparable to detecting changes in pauses or silent intervals between words, temporal fluctuations which may be more difficult to resolve in reverberated speech. Thus, aging seems to affect the ability to detect the rapid and impoverished acoustic cues present in temporally degraded speech, placing older adults at a disadvantage when they are listening in reverberant environments or to rapid speech. In accordance with the information-degradation hypothesis (Pichora-Fuller et al., 1995), the task of repeating compressed sentences may be more perceptually demanding for older listeners with temporal processing difficulties and therefore may consume additional resources that would otherwise be devoted to storage.

1.2.4 Reduced Working Memory/Resource Capacity

Aside from auditory processing ability, working memory also plays a crucial role in understanding spoken language (Daneman & Carpenter, 1980; Just & Carpenter, 1992). In order to interpret the combinations of word meanings in discourse, new information must be extracted

from the current input and related to the memory representation of earlier input. This task of integrating a sequence of words over time involves storage as well as manipulation of information in working memory, functions which compete for limited attentional capacity (Baddeley & Hitch, 1974). Just and Carpenter (1992) characterize this as a limited resource capacity for meeting the storage and computational demands of language processing.

Understanding of complex sentences requires simultaneous maintenance and computation of multiple grammatical and thematic relations in working memory (e.g. thematic role assignment). In this way, structurally complex sentences may place an especially heavy burden on the limited working memory capacity of older adults. Kemper (1986) found that older adults were particularly impaired at repeating complex (left-branching) sentences, which contain a long sentence-initial embedded clause (e.g. *The cookies* <u>*that I baked yesterday for my grandchildren*</u> *were delicious.*). This type of grammatical structure may be difficult for older adults to process because it imposes heavy demands on working memory resources. The embedded clause (underlined) interrupts the main clause, requiring the subject of the main clause (*the cookies*) to be retained in working memory while the embedded clause is being processed. Then the representation of the subject must be retrieved or reactivated at the conclusion of the embedded clause for integration with the matrix verb phrase (*were delicious*).

The findings of Norman et al. (1992) support the notion that there is a decline in working memory with advancing age which affects older adults' ability to process complex sentences. In their study, old-old adults (aged 75-92 years) scored lower than young-old adults (aged 60-74 years) and young adults (aged 18-26 years) on three measures of working memory: forward and backward digit span and reading span. Old-old adults also performed more poorly than the other two age groups on tests of reading comprehension when test passages contained a high incidence

of complex (left-branching) sentences. In addition to reading comprehension, older adults' ability to judge the grammatical acceptability of complex sentences is affected by an age-related reduction in working memory resources (Kemper, 1997). Kemper (1997) found that healthy older adults and those with probable Alzheimer's disease who exhibited lower digit spans were more likely than healthy young adults to rate grammatical complex sentences (e.g. *Plots by many conspirators who work for the government have been hatched.)* as unacceptable. These results suggest that reduced working memory resources in older adults may limit their ability to simultaneously retain and manipulate complex syntactic and thematic relations in working memory.

Another way to characterize age-related processing limitations is in terms of a reduction in the total amount of activation available in working memory (Just & Carpenter, 1992). Just and Carpenter's (1992) resource capacity theory of sentence processing proposes that there is a limited pool of activation resources devoted to simultaneous storage and manipulation of information as the listener processes the speech stream. The total amount of resources available must be allocated to each task at the different levels of language processing (e.g., lexical, semantic, syntactic). When total capacity is reduced, as in aging, resource demands for storage and processing are only partly met, resulting in a decline in storage function and/or speed of processing.

According to the total capacity hypothesis, task performance is affected only when processing demands exceed the available resource supply. Thus, age-related differences in language performance should be evident only when the comprehension task is demanding. Given that resource capacity may diminish in later adulthood (Light & Anderson, 1985; Norman et al., 1992; Stine and Wingfield, 1987), age-sensitive decrements in rapid speech processing and recall

are to be expected. The high demands of processing rapid speech are more likely to overload the limited resource capacity of older adults relative to younger adults.

1.2.5 Cognitive Slowing

Language comprehension involves successful integration of new information with prior input, a process which relies upon the availability of relevant information in working memory (Daneman & Carpenter, 1980). The availability of information in working memory is, in turn, dependent upon three factors: the rate of input, the rate of processing and the rate of decay in working memory. As new information is extracted from the incoming speech stream in listening comprehension, earlier information which is stored in working memory is subject to decay. When speech is time-compressed, there is a heavier demand on speed of processing as the listener must keep up with the high input rate. If the speed of processing falls below the input rate, then some information held in working memory may be lost or processed inadequately. Likewise, if processing speed falls behind the rate of decay, some items may decay before they are fully processed.

An age-related slowing in information processing has been cited as a major source of age differences in working memory (Salthouse & Babcock, 1991). In two studies involving independent groups of adults between 18 and 87 years of age, Salthouse and Babcock (1991) found significant negative correlations between age and two different measures of working memory. One working memory task involved solving arithmetic problems and recalling the single-digit responses and the other involved answering sentence comprehension questions and recalling the single-word responses. Participants also performed various tasks designed to assess different components of working memory. Storage capacity was assessed with digit span and

word span tasks while processing efficiency was assessed with arithmetic and sentence comprehension tasks. Coordination effectiveness was evaluated by performance on two concurrent processing tasks (i.e. selecting the correct answer to arithmetic problems or to questions about sentences while simultaneously remembering digits or words). Finally, simple processing speed was assessed in speeded comparison tasks, in which participants classified pairs of letters and line-segment patterns as "same" or "different" as rapidly as possible. Processing speed was evaluated in terms of the number of pairs correctly classified in the allotted time. Multiple regression analyses showed that, in comparison to measures of storage capacity, processing efficiency, and coordination effectiveness, the greatest attenuation of the age-associated variance in working memory measures occurred after statistically controlling for the simple speed measure. This suggests that age differences in working memory may be mediated by an age-related reduction in the speed of mental operations.

Cognitive slowing and the concomitant decline in working memory capacity may have a negative impact on cognitive functioning in later adulthood. Salthouse and Babcock (1991) hypothesize that age-related slowing of operations in working memory affects the quality of cognitive performance by reducing the amount of simultaneously available information. They propose that there is an age-related reduction in the rate at which information is activated but the rate at which it is lost or dissipated remains constant throughout adulthood. If decay rate remains constant but the rate of activation is reduced, then early information may no longer be available by the time later information has been processed.

Although age-related processing limitations have been characterized both in terms of slower processing rates (Salthouse & Babcock, 1991) and a reduction in working memory capacity (Just & Carpenter, 1992), it may be difficult to differentiate between the two accounts

of cognitive aging. Verhaeghen and Salthouse (1997) found that age-related differences on various measures of cognitive functioning (including episodic memory and reasoning) were mediated by both processing speed and working memory. Furthermore, a hierarchical regression analysis revealed that a large proportion of age-related variance in the cognitive variables that was related to processing speed was also shared to a great extent with working memory capacity. This suggests that age-related effects on cognitive performance, such as speed of processing and working memory, are not independent of one another but rather they may be linked by a single common factor. This finding is consistent with the common cause hypothesis, which proposes that declines in both perceptual and cognitive functioning may reflect widespread neural degeneration (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994, as cited in Schneider & Pichora-Fuller, 2000). Likewise, Birren et al. (1980) reviewed evidence which suggests that the slowing of behaviour with age is not only evident in motor and sensory processes but becomes more apparent with increasing complexity of behaviour. This general slowing in speed of behaviour, they argued, may be a reflection of neurobiological changes in the central nervous system.

Processing speed undoubtedly plays an important role in listening comprehension, especially at fast speech rates. Rapid input presents a challenge to slowed processing systems by reducing the amount of time available for analyzing the acoustic signal. Wingfield (1996) emphasizes loss of processing time as a primary reason for older listeners' difficulty with compressed speech.

1.2.6 Perceptual Adaptation to Compressed Speech

In light of research which suggests that aging imposes a limitation on the ability to process rapid speech, the provision of additional processing time has been examined as a way of minimizing the deficit (Schmitt, 1983; Schmitt & Carroll, 1985; Schmitt & Moore, 1989; Wingfield et al., 1999). However, the results provide little support for a facilitating effect of either slower rate or pausing (see page 5). As an alternative to slowing down speech rate or pausing between phrases, one can ask whether older listeners themselves can learn to adapt to rapid speech through repeated exposure to it. Research has demonstrated such perceptual adjustment to rapid speech in younger listeners. Voor and Miller (1965) found that passage comprehension improves over the first 8 or 10 minutes of practice listening to compressed speech, after which performance plateaus. Other researchers have found that adjustment to compressed speech occurs over a much shorter course of 10 to 15 sentences, with little improvement thereafter (Mehler et al., 1993; Dupoux & Green, 1997).

Dupoux and Green (1997) conducted experiments which examined the nature of perceptual adjustment to compressed speech. Their first experiment focused on the slope of adjustment as a function of the amount of exposure to compressed speech. Their stimuli consisted of 10-word sentences, which were artificially time-compressed to 38% and 45% of their original durations. Sentences were divided into four sets of five sentences and presented to individual college-age participants over loudspeakers. Participants were instructed to listen to each sentence and write down as much of it as they could recall. The proportion of content words correctly recalled from each sentence were computed and averaged over the five sentences of each set to yield four set scores for each participant. The results showed an increase in recall scores across the different sentence sets at both compression rates. However, the two

compression rates produced different rates of improvement with participants reaching a plateau in performance faster at 45% compression than at 38% compression. This indicates that habituation to compressed speech occurs over the course of a few sentences but that the slope of the function depends on the compression rate. A higher compression rate of 38% required more experience than 45% compression before complete adjustment was achieved.

In the second experiment by Dupoux and Green (1997), the same sets of five sentences were presented at 38% compression but participants heard two sets produced by one talker and a third set produced by a different talker. As in Experiment 1, the results revealed an improvement in recall performance across the sentence sets. However, there was a slight drop in recall immediately after a change in talker, which then showed rapid recovery over the remaining sentences in the set. This demonstrated that a sudden change in talker had minimal, short-lived effects on the adjustment process. Experiment 3 investigated whether an abrupt shift in compression rate from highly compressed speech to uncompressed speech would influence the adaptation process. Participants first heard ten sentences compressed to 38% of their original duration. Then five new uncompressed sentences were presented, followed by five new sentences at the original 38% compression rate. The results showed only a small decline in performance immediately after the switch back to compressed speech. As in Experiment 2, this decrease occurred on the first two sentences following the change, after which performance returned to the previous adapted level. The results of these two experiments indicated that abrupt changes in talker characteristics and speaking rate had little effect on the adaptation process. These changes only resulted in a temporary drop in performance, a finding which Dupoux and Green (1997) attributed to the occurrence of normalization processes (Miller, 1981; Miller & Liberman, 1979).

In order to maintain perceptual constancy, listeners use normalization mechanisms to compensate for the instability of speech cues due to contextual factors, such as talker characteristics and speech rate. For instance, there is considerable variation in articulation rate during conversational speech, even within a single utterance of a particular speaker (Miller, Grosjean, & Lomanto, 1984). Studies have shown that changes in speech rate have a great impact on the realization of temporal acoustic cues such as transition duration, closure duration, voice onset time (VOT), and vowel duration, and that the human perceptual system interprets these cues according to utterance rate (Miller, 1981; Miller & Liberman, 1979). For example, syllables beginning with short initial transitions are perceived as beginning with a stop consonant (e.g. /ba/) whereas those with longer transitions are perceived as beginning with a semivowel (e.g. /wa/). As articulation rate decreases and /ba/ becomes longer, transition duration remains relatively constant whereas the transition duration in /wa/ increases as syllable duration increases. Miller and Liberman (1979) demonstrated that listeners process transition duration in relation to speech rate: as speech slows down and syllable duration increases, the transition duration necessary to perceive /wa/ as opposed to /ba/ also increases. Thus, speech cues such as transition duration are normalized with respect to the rate at which speech is articulated. Such rate normalization processes occur instantaneously and automatically in response to local variations in the speech signal.

Dupoux and Green (1997) examined whether adaptation to compressed speech simply reflects short-term rate normalization processes or a perceptual learning process. They noted that if perceptual adjustment to compressed speech reflects short-term adjustments in the form of normalization processes, the presentation of uncompressed materials after complete adjustment has been attained should reset the perceptual system to the normal speech rate. When

compressed speech is again presented, the system should readjust to the rapid speech rate. The slight and immediate decline in performance that Dupoux and Green (1997) found in response to a change in talker or compression rate may reflect the effect of such normalization mechanisms. However, the fact that performance recovered very quickly suggests that adaptation to compressed speech may also be related to a perceptual learning process.

1.2.7 Age-Related Changes in Perceptual Skill Learning

In their investigation of age differences in perceptual skill learning, Hashtroudi et al. (1991) found older adults may be impaired in improving a perceptual skill when the stimuli are perceptually demanding. They found that, in comparison to younger adults, older adults showed less improvement in the skill of reading inverted words and no improvement on a partial-word identification task with practice. However, this age deficit in skill learning was eliminated when older adults were presented with more perceptual information, either by increasing word presentation time or by presenting less degraded words, respectively. Hashtroudi et al. (1991) suggest that this may reflect an age-related deficit in the ability to process complex or poorer quality input.

When input rate is accelerated through time-compression of the speech material, it results in distortion or degradation of the input. It is reasonable to assume that the degree to which speech stimuli are compressed determines the extent of input degradation such that the higher the speech rate, the more distortion is introduced into the speech signal. Previous research shows that age-related differences in rapid speech processing are especially evident at rapid input rates of around 300 wpm (a compression rate of about 60%) and higher (Stine & Wingfield, 1987; Stine et al., 1986). At such accelerated rates, temporal acoustic cues become highly distorted and

extremely reduced in duration, resulting in heightened perceptual stress for older listeners with limited temporal processing abilities. Given that adaptation to compressed speech is a form of perceptual skill learning (Dupoux & Green, 1997) and that compressed speech is perceptually demanding, older adults are expected to show less improvement than young adults in the skill of repeating compressed sentences with practice.

1.3 Summary

Studies have shown that in tests of listening comprehension, time-compressed speech affects the performance of older listeners more than that of younger listeners. The heavy demands of processing rapid speech may differentially impair older adults due to age-related deficits in auditory temporal processing, cognitive processing speed, and working memory capacity. The implications of these findings for performance in the real world, where speech rates can easily exceed 200 wpm, are clear. Indeed, older listeners often complain that they have difficulty understanding rapid speech. It has been suggested that comprehension by older listeners might be improved by reducing the rate of speech; however, experimental findings indicate that slower-than-normal speech rates do not reliably enhance comprehension for older listeners.

As an alternative to slowing down speech, the present study asks whether older listeners can learn to adapt to rapid speech through repeated exposure to it. Research has demonstrated such perceptual adjustment to compressed speech in younger listeners. In the present study, the effects of practice will be examined by measuring younger and older listeners' recall performance following various amounts of experience with compressed sentences. It is hypothesized that older listeners' ability to recall compressed sentences will improve with

practice. However, they are expected to improve to a lesser degree and at a slower rate than younger listeners due to age-related deficits in temporal/perceptual and cognitive processing.

1.4 Research Hypotheses

Hypothesis 1. It is hypothesized that recall performance for both age groups will be poorer at the compressed rate than at the normal rate. Time-compression of speech stimuli exacerbates processing demands and has a detrimental effect on recall performance.

Hypothesis 2. It is hypothesized the recall performance of older participants will be poorer than that of younger participants at the compressed rate. Compression of speech material has been shown to affect older listeners' comprehension and memory for speech more than that of younger listeners due to age-related decrements in temporal processing, speed of processing, and/or working memory capacity.

Hypothesis 3. It is hypothesized that recall of compressed sentences will increase through practice for both younger and older participants. Such an improvement would provide evidence that experience with compressed speech results in perceptual adaptation.

Hypothesis 4. It is hypothesized that older participants will show a slower rate of improvement in recall than younger participants due to the effects of cognitive slowing. That is,

older listeners' performance will take longer to reach asymptote than that of younger listeners.

Hypothesis 5. It is hypothesized that older participants will show less improvement with practice than younger participants. Comprehension of compressed speech involves processing of complex perceptual information. It is likely, then, that age-related deficits in temporal processing will limit the extent to which older listeners can adjust to compressed speech.

Hypothesis 6. It is hypothesized that during the adaptation process, a sudden change to uncompressed speech will only result in a slight decline in recall scores immediately following the change, after which performance will return to the previous adapted level. Such a recovery would provide evidence that perceptual adjustment to compressed speech is related to perceptual learning.

Hypothesis 7. It is hypothesized that there will be a negative correlation between gap detection thresholds and recall performance at the compressed rate but not at the normal rate. Temporal processing ability affects speech perception, especially when temporal acoustic cues are distorted due to time-compression of the signal.

Hypothesis 8. It is hypothesized that there will be a positive correlation between measures of working memory and recall performance. Working memory plays an important

role in listening comprehension, which requires simultaneous processing and storage of information.

Hypothesis 9. It is hypothesized that there will be a negative correlation between reaction time (as a measure of speed of processing) and recall performance. Speed of information processing is an important factor in listening comprehension because the listener must keep up with the continuous flow of information in the speech stream.

2. CHAPTER TWO: METHOD

2.1 Participants

Younger participants were 10 student volunteers (3 men, 7 women) from the University of British Columbia, ranging in age from 20 to 30 years (M = 22.3 years, SD = 3.1). The group had 14 to 19 years of education (M = 15.8, SD = 1.4). Their scores on the Shipley (1940) vocabulary test (see Appendix A) ranged from 57.5% to 87.5% correct (M = 78.5% , SD = 9.2).

Older participants were 10 community-dwelling adult volunteers (5 men, 5 women), with ages ranging from 62 to 78 years (M = 70.4 years, SD = 5.3). All were high school graduates, with 12 to 18 years of education (M = 14.3, SD = 2.2). Their Shipley vocabulary scores ranged from 70% to 97.5% (M = 92%, SD = 8.2). Older participants thus had an advantage over younger participants with respect to vocabulary scores (t (18) = 3.45, p = .003) but the two groups did not differ significantly in terms of mean years of education (t (18) = -1.81, p > .05). Background characteristics of individual participants are provided in Appendix B.

Each participant completed a questionnaire regarding his or her hearing, health, and language history (see Appendix C). All participants were native speakers of English with no recent history of significant medical problems, such as cerebro- or cardiovascular accidents, that might impair cognitive functioning. All participants' hearing was generally within normal limits for their age group, as determined by audiological testing. In order to account for presbycusis or high-frequency hearing loss associated with aging, pure-tone air-conduction thresholds greater than the 25 dB HL criteria level were permitted above 3000 Hz for older participants. All but two of the participants demonstrated thresholds less than or equal to 25 dB HL from 250 to 3000 Hz. The two exceptions were older participants who demonstrated thresholds slightly higher than 25

dB HL at 250 Hz and 500 Hz monaurally. However, their Speech Reception Thresholds were less than 25 dB HL for both ears. Audiometric thresholds are provided in Appendix D.

All volunteers were paid $15 for their participation in the study.

2.2 Materials

2.2.1 Sentence Recall Stimuli

Forty sentences were constructed for the pilot experiment. Because a lower compression rate was used in this experiment (see below for rationale) compared to previous research (e.g. Dupoux & Green, 1997; Stine, Wingfield, & Poon, 1986), longer sentences were constructed in order to avoid ceiling effects in recall performance. If participants' initial performance were near ceiling, then it would be impossible to measure improvement in performance over time as a result of experience.

Each sentence consisted of 16-18 words (M = 17.24, SD = .83), 24-28 syllables (M = 26.16, SD = 1.33), 2 clauses (1 independent and 1 dependent), and 8-10 propositions (M = 8.56, SD = .73). Propositional representations for sentences were constructed using a system developed by Kintsch (1974) and modified by Turner and Greene (1977). An example of a sentence containing 8 propositions is shown below, along with its propositional representation. Each proposition is enclosed by parentheses and is composed of a predicate (typically a verb) or relation plus one or more arguments. Arguments are usually nouns or other embedded propositions, which are denoted by their reference number.

Sample Sentence and Its Propositional Representation

The leak under the kitchen sink was not repaired until the angry tenants threatened to move out.

1. *(sink, kitchen)*
2. *(tenants, angry)*
3. *(under, leak, sink)*
4. *(repaired, x, leak)*
5. *(repaired, not)*
6. *(move out, tenants)*
7. *(threatened, tenants, 6)*
8. *(until, 4, 7)*

A variety of syntactic constructions were used, including subordinate clauses, Wh-clauses, and relative clauses. No numbers, proper names, or compound, rare, and foreign words were used, and none of the sentences were semantically anomalous. For the purpose of norming, the sentences were presented in written format to a group of five participants who rated the semantic plausibility of each sentence on a scale from 1 (*very unlikely*) to 7 (*very likely*) (Dupoux and Green, 1997). A *very likely* sentence describes an ordinary event that has a high probability of occurring in everyday life while a *very unlikely* sentence describes a bizarre event that is not very likely to occur. Sentences given a rating of 3 or below by more than one rater were rewritten. See Appendix E for a list of sentence stimuli and their propositional representations.

The sentences were then recorded directly onto a Windows-based PC computer at a 44,100 sampling rate (16 bit quantization) using a sound editing program (Cool Edit 2000). Naturally spoken rapid speech as opposed to artificially accelerated speech was used since the former sounds more natural and is not subject to waveform distortions introduced by artificial time-compression methods. Sentences were spoken by the author at a normal rate of 180 wpm

and at 68% time-compression in a double-walled sound-attenuating IAC booth. The microphone (from Creative SoundBlaster Live) was positioned approximately six inches from the mouth.

At a compression rate of 68%, sentences are reduced to 68% of their original duration to produce an accelerated speech rate of 265 wpm. The 68% compression rate was chosen for two reasons. First, previous research shows that this is the rate at which age differences in recall performance begin to appear (e.g. Stine et al., 1986). At this rate, recall scores between 80% and 85% had been found in younger listeners. Given that adaptation to compressed speech had been shown to lead to an increase of 10-15% in recall accuracy (e.g. Dupoux & Green, 1997), initial scores in the 80-85% range would allow performance to improve to the level observed at the uncompressed or normal rate (i.e. around 95%). Secondly, 265 wpm is within the normal range of rate variation, thereby permitting stronger inferences concerning the effect of rate on speech comprehension in real world contexts.

2.2.2 Working Memory Tasks

Participants were tested on two measures of working memory: the listening span task and the backward digit span task.

2.2.2.1 Listening Span Task

The listening span task, as described by Daneman and Carpenter (1980), was employed in the present study. It is a common measure of working memory and has been found to be correlated with other working memory tasks, including reading span (Daneman & Carpenter, 1980; Daneman & Merikle, 1996). The listening span materials consisted of 100 sentences (see Appendix F). The sentences were divided into five span levels (two through six). Each span level

consisted of five trials, with the number of sentences in each trial corresponding to the span level (for example, at span level three, each of the five trials consisted of three sentences). Sentences were presented binaurally over headphones at a comfortable listening level and participants were asked to verify whether each sentence was true or false. At the end of each trial, the participant was asked to recall the final word of each of the sentences in the trial. The test was terminated when the participant failed to recall all final words in four out of five trials. Listening span was defined as the longest span level for which a participant was able to correctly recall all final words in at least three out of five trials. If a participant correctly recalled two out of five trials, he or she was given a credit of 0.5.

2.2.2.2 Backward Digit Span Task

Another widely used measure of working memory, the backward digit span task (Wechsler, 1987), was also employed in this study. Small and his colleagues have found that it correlates well with sentence processing and with other working memory measures (Small, Andersen, & Kempler, 1997; Small, Kemper, & Lyons, 2000). In this task, participants repeat progressively longer series of numbers in backwards order. They start by repeating two digits at level one and continue repeating longer series of numbers (maximum of seven at level six) until neither of two trials at a level are repeated correctly. Digit span was scored in two ways. In the standard procedure, participants are given one point for each correctly repeated sequence and their digit span is determined by adding up the total number of points. Following Small and his colleagues, digit span was actually defined as the longest sequence which the participant was able to correctly recall at least one of two trials. This definition of digit span seems to be more representative of actual span size than the standard scoring procedure of totaling the number of

correctly repeated sequences. For example, if a participant was successful at recalling both trials at levels one through four (digit spans two through five), his or her span size would be five. Under the standard scoring procedure, the score would have been eight, a number that does not correspond to the actual size of the person's digit span.

2.3 Procedure

2.3.1 Experimental Procedure

A pilot experiment was conducted to determine whether the sentences would yield the expected recall accuracy of approximately 95% at the uncompressed rate and 80-85% at the compressed rate. Another purpose of the pilot experiment was to examine how many sentences participants would require to reach a plateau in their adaptation. Based on previous research (e.g. Dupoux & Green, 1997), it was expected that subjects would reach plateau within 10-15 sentences. A third goal of the pilot study was to rule out the possibility that recall performance improves with increased exposure to compressed sentences simply due to practice with the recall task itself.

A group of eight adults participated in the pilot study. They were instructed to listen to each sentence and then to recall it out loud as accurately as possible. Guessing was encouraged. In order to rule out task-related practice effects, half of the pilot participants heard a block of 10 sentences at the normal rate followed by a block of 30 sentences at the compressed rate while the other half heard the two blocks of sentences in the reverse order. Their responses were audiotaped for later transcription and scoring. Recall accuracy of the first 10 compressed sentences was computed. If recall of compressed sentences improves due to task-related practice effects rather than adaptation to fast rate, then those participants who experience the 10 normal

rate sentences prior to the compressed block should perform better than those without any prior experience with the recall task. Results showed that the two (block order) groups did not differ significantly in terms of recall performance on the first 10 compressed sentences, thereby providing evidence against general task-related practice effects. Results also showed expected recall accuracy rates of 95% and 80-85% for uncompressed and compressed rates, respectively. In addition, participants who showed rate adaptation in the compressed block seemed to adjust to the fast rate within 10-15 sentences as expected.

Based on these pilot study results, five more sentences were constructed using the same criteria as before. The total set of 45 sentences was divided into three blocks of 15 sentences each. There were two Compressed Rate blocks in which sentences were recorded at the compressed rate of 265 wpm and one Normal Rate block with sentences recorded at 180 wpm. A Compressed Rate/Normal Rate/Compressed Rate block order was used, with the presentation order of the two Compressed Rate blocks counterbalanced such that half of the participants in each age group were presented with one order and the remainder the other order.

The experiment was run on a Windows-based PC computer using E-Prime (a software program developed by Psychology Software Tools, Inc.). The 15 sentences in each block were presented binaurally in a random order to individual participants over JVC HA-D30 headphones in a double-walled, sound-attenuating IAC booth. Prior to the main experiment, the intensity level was adjusted to a comfortable listening level for the participant. Each of the three blocks was preceded by a single practice sentence presented at the corresponding speech rate. None of these three practice sentences were part of the experimental set of forty-five. Participants were instructed to listen to each sentence and recall as much as of it out loud as they could. They were encouraged to guess if need be. Responses were audiotaped for later transcription and scoring.

Reaction times were automatically recorded using the voice-activated function (voice key) on a Serial Response Box connected to the computer. Reaction times were measured from the offset of each sentence stimulus to the time of the initiation of a verbal response and were used as a measure of speed of processing.

2.3.2 Gap Detection Test Procedure

In addition to audiological testing, basic auditory temporal processing ability was determined using the gap detection test procedure outlined in Schneider et al. (1994). The materials for this test were provided by Bruce Schneider from the University of Toronto at Mississauga. The materials consisted of 2-kHz tonal gap and no-gap stimuli. The stimuli were constructed digitally and sampled at a rate of 20 000 Hz. The amplitude envelope of both the preceding and following gap markers was obtained by summing a number of temporally distributed Gaussian envelopes, each with an envelope standard deviation of 0.5 ms and spaced at 0.5 ms intervals. The rise and fall time of the stimuli was held constant. The peak amplitude of each set of envelopes was held constant at 1.0. Each set of summed Gaussian envelopes was then multiplied by a 2-kHz tone. The gap duration was defined as the duration from the last peak in the first marker to the first peak in the lagging marker.

The gap detection stimuli were presented in a two-interval forced-choice paradigm. On each trial, the listener was presented with two acoustic intervals, one of which contained a gap and one containing a continuous signal of the same duration and the same total energy. The listener's task was to indicate which of the intervals contained a gap by pressing one of two buttons on a three-button response box. Signal lights marked each tone presentation and also provided immediate feedback as to the accuracy of each response. The initial gap size at the

beginning of each trial was 36 ms. The gap size was either increased or decreased according to a 3 down 1 up rule. Following three correct responses at a level, the gap size was decreased. Following each incorrect response, gap size was increased. Each test run was completed following 12 reversals. The mean of the last eight reversals was the gap detection threshold for that run. Four runs were completed by each subject, with the first run used to familiarize the listener and therefore not included in data analysis. The final gap detection threshold was taken as the mean threshold from the second, third and fourth runs. The instructions for the gap detection test can be found in Appendix G.

This measure of temporal resolution was used because it taps an aspect of auditory temporal processing that seems most relevant to the perception of compressed speech. Individual participant data for the gap detection test and other experimental measures are provided in Appendix H.

2.4 Analysis

Sentences were scored in two ways. First, the proportion of words correctly recalled was computed. That is, the number of words correctly repeated was divided by the total number of words in the sentence (including all content and function words). Any form of the noun or verb was allowed. That is, missing or added plural endings and verbal inflections were not counted as errors. Furthermore, any word order was allowed and added words were not scored as errors.

Sentences were also scored for the percentage of propositions correctly recalled. Wingfield, Tun, and Rosen (1995) found that, in immediate recall, participants' responses contained word substitutions and paraphrases of the original utterance. This suggests that participants recall the propositional content of sentences and not just the surface string. Potter

and Lombardi (1990) demonstrated that immediate sentence recall involves regenerating the surface representation from a representation of sentence meaning using recently activated words. They tested this regeneration hypothesis by presenting a lure (a synonym of the target word in the sentence to be recalled) in an distractor task either immediately before or after the sentence. In contrast to the high accuracy with which other words were recalled, the target word was frequently replaced by the synonym lure in recall. That is, presentation of the lure word activated its lexical entry and increased the probability that it would intrude or be selected in recall. The results also showed that the synonym sometimes intruded spontaneously when not presented as a lure. This supports the hypothesis that immediate recall is based on sentence meaning and not only on a representation of the surface form. However, activating the synonym by presenting it as a lure substantially increased the intrusion rate, consistent with the claim that recently activated words are preferentially chosen for recall. This accounts for the verbatim or near-verbatim nature of immediate sentence recall in that the original lexical items are likely to be the most recently activated words. By scoring responses in terms of both word and propositional recall in the present study, the recovery of both verbatim and conceptual content were taken into account.

A proposition was scored as correct if the main gist of it was preserved in the recall. If an argument appearing in more than one proposition was incorrectly recalled, only one of those propositions was counted as incorrect. For example, if the eight-proposition sentence above had been recalled as "The leak under the kitchen sink was not repaired until the angry <u>couple</u> threatened to move out," the only proposition that would be counted as an error would be the second one (i.e. *tenants, angry*).

Both word recall and propositional recall data were examined, and the two were found to be highly correlated ($r = .99$, $p < .0001$). Therefore, only word recall data will be reported in the current study.

The mean proportion of words correctly recalled in each block of 15 sentences was calculated for each participant (clear outliers or scores that were three or more standard deviations above or below the mean were excluded). This mean plus and minus two standard deviations were designated the maximum and minimum value respectively. Scores within each block that were more than two standard deviations above the mean were replaced with the maximum value and those more than two standard deviations below the mean were replaced with the minimum value. A new mean was then calculated and any missing scores (clear outliers) were replaced with this new mean. In this way, 3.6% of all extreme word recall scores were adjusted and 1.2% missing scores replaced. Using the same method (adapted from Tyler (1992)), 5.1% of all reaction time scores were adjusted and 3.8% missing reaction time scores replaced.

3. CHAPTER THREE: RESULTS

In the following sections, word recall results will be discussed in terms of rate compression effects and adaptation effects. Subsequently, the results of gap detection, working memory, and reaction time measures will be discussed in relation to recall performance.

3.1 Recall Performance

3.1.1 Rate Effects

In order to examine the effect of Rate on word recall performance, recall scores were collapsed across the two Compressed Rate blocks to produce the mean recall of compressed sentences. An analysis of variance (ANOVA) was then conducted with Rate (compressed vs. normal) as a within-subject factor and Age (young vs. old) as a between-subject factor. As shown in Figure 1, the results revealed a marginal main effect of Rate (F (1, 18) = 4.58, p = .05) and a Rate X Age interaction that did not reach significance (F (1, 18) = 3.57, p = .08).

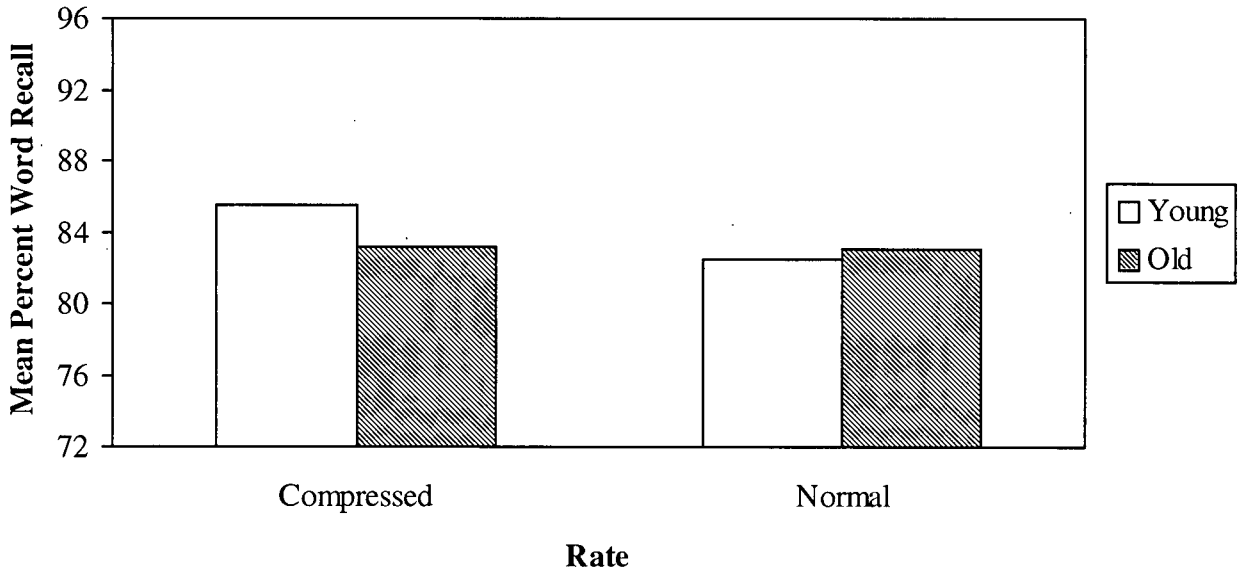

Figure 1. Mean word recall by rate for all young and old participants.

Surprisingly, the effect of Rate was in the direction opposite to that reported in the literature. Word recall performance was slightly better in the Compressed Rate condition than in the Normal Rate condition (84.4% vs. 82.8%). That is, acceleration of speech rate did not impair word recall performance as hypothesized. Mean recall accuracy of the older group was slightly lower than that of the younger group at the compressed rate while there was virtually no difference in performance at the normal rate. However, an unpaired *t* test revealed that older participants' recall performance at the accelerated rate was not significantly poorer than that of the younger group (t (18) = -.50, p > .10), contrary to what was predicted. (Means and standard deviations of word recall and other experimental measures for the two age groups are provided in Table 1.)

EXPERIMENTAL MEASURE	YOUNG		OLD		
	M	SD	M	SD	p
% Word Recall (Overall)	84.53	7.86	83.15	11.89	.76
% Word Recall (Compressed Rate)	85.53	7.64	83.21	12.52	.62
% Word Recall (Normal Rate)	82.52	8.47	83.03	11.08	.91
Listening Span	3.25	1.14	1.85	.97	.008
Digit Span	5.8	1.03	5.0	1.33	.15
Reaction Time (s)	1.03	.81	1.31	.57	.37
Gap Detection Threshold (ms)	3.89	1.1	5.73	1.52	.007

Table 1. Means and standard deviations of experimental measures for young and old participants.

3.1.2 Adaptation Effects

Each block of 15 sentences was divided into three sets of five sentences. Word recall scores were averaged over the five sentences of each set to yield nine Set Means across all 45 sentences for each participant (as depicted in Table 2).

SET	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9
# OF SENTENCES PER SET	5	5	5	5	5	5	5	5	5
RATE	Compressed			Normal			Compressed		

Table 2. Nine sets of five sentences presented in a Compressed Rate/Normal Rate/Compressed Rate block order.

Of primary interest was whether there was any increase in recall from one Set Mean to the next in the first Compressed Rate block. Such an improvement would suggest that experience with compressed speech resulted in perceptual adaptation. The results of an ANOVA with Set Position (1-3) (sentence sets 1 through 3) as a within-subject factor and Age (young vs. old) as between-subject factor showed that neither the main effect of Set Position, nor its interaction with Age, was significant (F (2, 36) = .61, $p > .10$ and F (2, 36) = .26, $p > .10$, respectively) (see Figure 2).

However, further analysis showed that a subset of the participants did demonstrate perceptual adjustment to the compressed rate: O-2, O-3, O-4, O-5, O-6, O-8, O-9, Y-1, Y-3, Y-6, Y-8, Y-9, Y-10 (see Appendix I). These participants' Set 3 Mean Recall was greater than their Set 1 Mean Recall. An ANOVA conducted on only this subset of 13 participants (7 old, 6 young)

revealed a significant rise in recall scores from one sentence set to the next in the first compressed block (F (2, 22) = 6.61, p = .006), as shown in Figure 3.

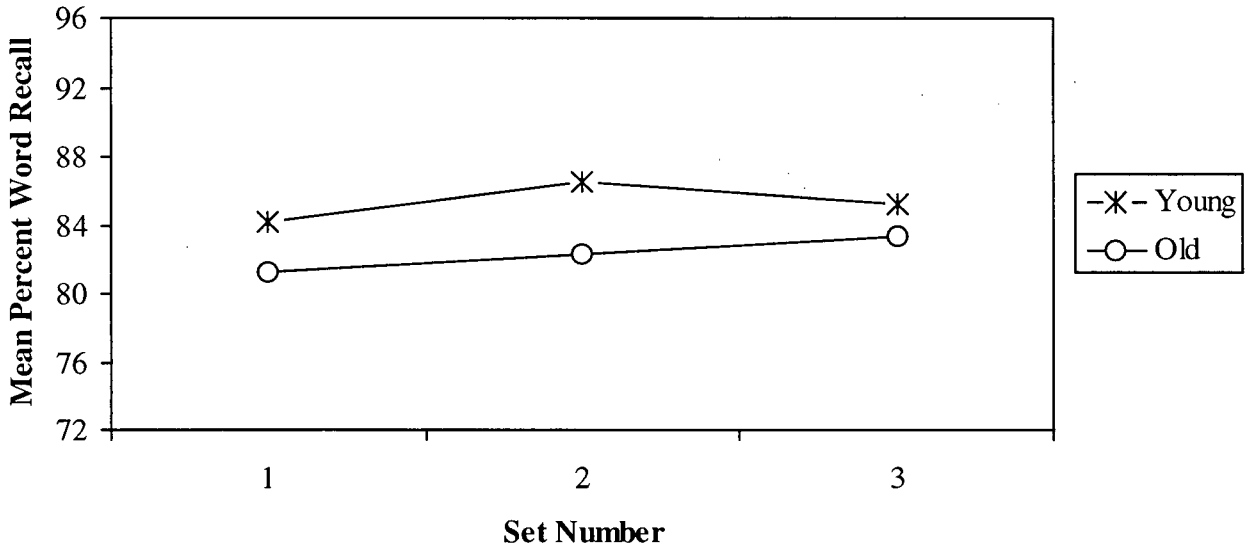

Figure 2. Mean word recall by set position for all young and old participants in the first compressed rate block.

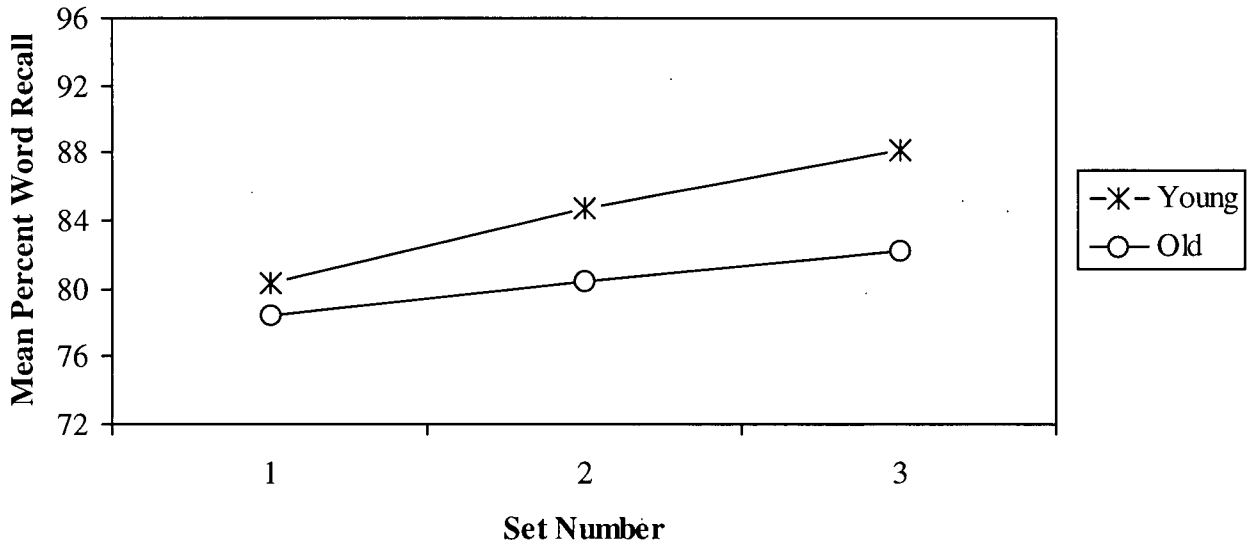

Figure 3. Mean word recall by set position for adapting young and old participants in the first compressed rate block.

Mean word recall by set position for each participant in the first compressed rate block is shown in Appendix I.

Although there was a tendency for the younger group of adapting participants to exhibit a greater rate and extent of improvement, this did not result in a significant Set Position (1-3) X Age interaction (F (2, 22) = .81, p > .10). The main effect of Set Position was not significant in the other two blocks (F (2, 22) = .42, p > .10 and F (2, 22) = .74, p > .10). Mean word recall for adapting young and old participants in all three blocks is shown in Figure 4.

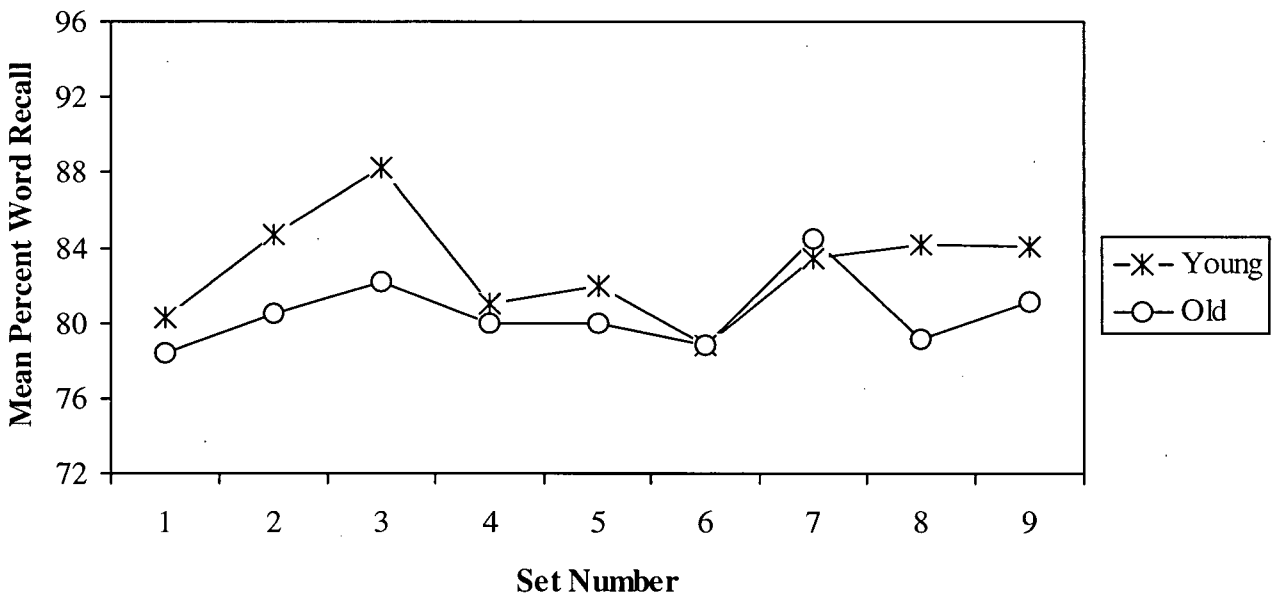

Figure 4. Mean word recall by set position for adapting young and old participants in all three blocks.

Interestingly, participants who showed adaptation to compressed speech obtained lower overall word recall scores (t (18) = 1.40, p > .10), listening span scores (t (18) = 1.19, p > .10), and digit span scores (t (18) = 1.24, p > .10) than those who did not show adaptation although none of these group differences reached statistical significance (see Table 3).

EXPERIMENTAL MEASURE	Adapting Participants		Non-adapting Participants		
	M	SD	M	SD	p
% Word Recall (Overall)	81.64	11.00	87.92	5.88	.18
Listening Span	2.31	1.36	3.00	.96	.25
Digit Span	5.15	1.28	5.86	1.07	.23

Table 3. Means and standard deviations of overall word recall and working memory measures for adapting and non-adapting participants.

In order to examine whether there was an immediate decline in performance following the change to an uncompressed rate (for participants who showed adaptation), a paired *t* test was conducted between Set 3 Mean Recall and the mean proportion of words correctly recalled in the first two sentences of the second Compressed Rate block (Set 7). The results indicated that there was no immediate drop in performance following the intervening uncompressed stimuli (t (12) = .70, $p > .10$) as was observed in Dupoux and Green (1997). A paired *t* test also revealed no significant difference between Set 3 Mean Recall (the last set of the first Compressed Rate block) and the entire Set 7 Mean Recall (the first set of the second Compressed Rate block) (t (12) = .40, $p > .10$). This shows that the improvement in recall scores which occurred in the first Compressed Rate block was maintained despite the intervening block of uncompressed sentences.

3.2 Gap Detection Thresholds

Gap detection thresholds less than 10 ms were obtained for all participants except for one older participant (see Appendix G). An unpaired *t* test revealed a significant difference between young and old participants on the gap detection test (t (17) = 3.06, p = .007). The mean gap detection threshold of the older group (5.73 ms) was higher than that of the younger group (3.89 ms). To examine the effect of gap detection ability on word recall performance, participants were divided into a low gap detection threshold group (thresholds less than 4.50 ms, N = 10) and a high gap detection threshold group (thresholds equal to or greater than 4.50 ms, N = 9). An ANOVA with Rate (compressed vs. normal) as a within-subject factor and Gap Detection Threshold (low vs. high) as a between-subject factor revealed a significant Rate X Gap Detection Threshold interaction (F (1, 17) = 5.92, p = .03) (see Figure 5).

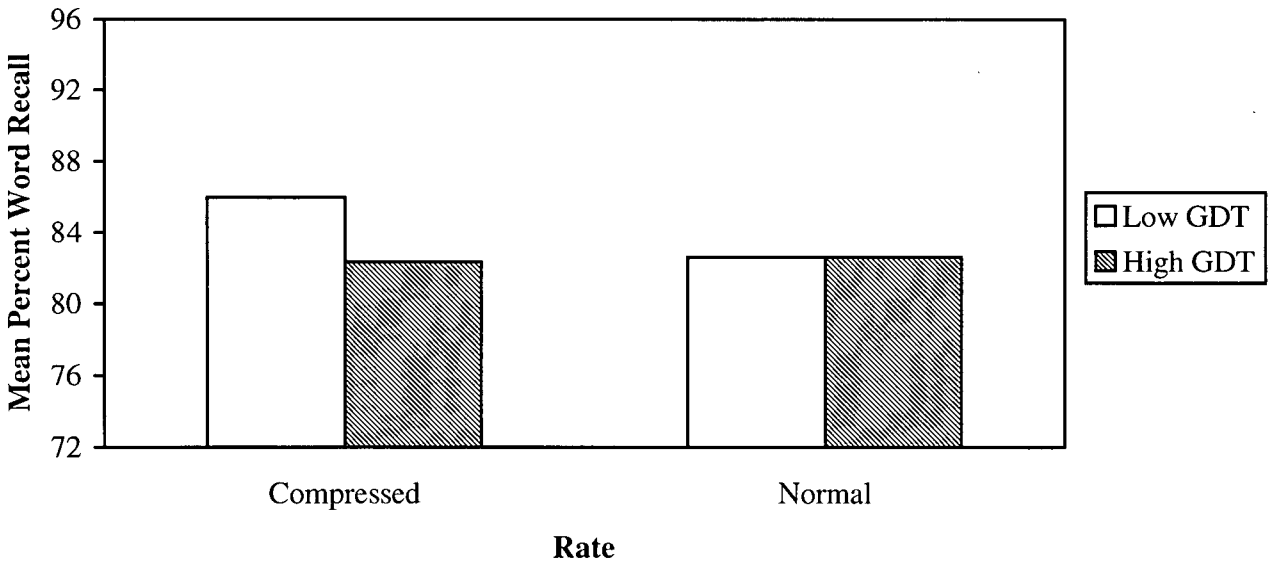

Figure 5. Mean word recall by rate for low and high gap detection threshold participants. GDT = gap detection threshold.

At the compressed rate, participants with a low gap detection threshold performed better than those with a high threshold but there was no difference in performance at the normal rate. Furthermore, correlation analysis revealed a significant negative correlation between gap detection thresholds and recall accuracy at the compressed rate ($r = -.54$, $p = .02$) but not at the normal speech rate ($r = -.35$, $p > .10$). This indicates that auditory temporal processing ability, as measured by the gap detection test, is specifically related to the recall of compressed stimuli. Correlations among experimental measures for all participants are provided in Table 4.

3.3 Working Memory Scores

Unpaired *t* tests revealed a significant difference between young and old participants on the listening span test (t (18) = -2.96, $p = .008$) but not on the digit span backward test (t (18) = -1.50, $p > .10$). The mean listening span score of the younger group (3.25) was higher than that of the older group (1.85). Given that age group did not discriminate word recall performance, in order to further examine the relationship between working memory and word recall, participants were divided into a high listening span (HiSpan) group (spans equal to or greater than 3.0, N = 9) and a low listening span (LoSpan) group (spans less than 3.0, N = 11). Each span group included both younger and older participants. The mean proportion correct recall of the HiSpan group (87.4%) was higher than that of the LoSpan group (80.9%) but this difference failed to meet statistical significance, likely due to the small sample size (t (18) = -1.51, $p > .10$). When comparing the performance of high span and low span participants, those with a high digit span (spans equal to or greater than 6.0, N = 11) showed a higher mean proportion correct recall (86.2%) than the low digit span (spans less than 6.0, N = 9) group (80.9%) but again the difference was not significant (t (18) = -1.21, $p > .10$).

	Listening Span	Digit Span	Reaction Time	Gap Detection Threshold	Word Recall (Overall)	Word Recall (Compressed Rate)	Word Recall (Normal Rate)
Listening Span	--						
Digit Span	.49**	--					
Reaction Time	-.52**	-.02	--				
Gap Detection Threshold	-.41*	-.41*	.26	--			
Word Recall (Overall)	.60***	.52**	-.65***	-.49**	--		
Word Recall (Compressed Rate)	.61***	.53**	-.65***	-.54**	.99***	--	
Word Recall (Normal Rate)	.54**	.48**	-.62***	-.35	.97***	.94***	--

*$p < .10$

**$p < .05$

***$p < .01$

Table 4. Correlations among experimental measures for all participants.

Given the small samples in high and low span groups, correlation analyses were conducted to examine the continuum of covariance between working memory and word recall. These analyses revealed that both working memory measures significantly correlated with word recall performance ($r = .60$, $p = .006$ for listening span and $r = .52$, $p = .02$ for digit span). There was also a significant correlation between listening span scores and digit span scores ($r = .49$, $p = .03$), as shown in Table 4.

3.4 Response Latency

An ANOVA was conducted on reaction time data (from the sentence recall task) with Rate (compressed vs. normal) as a within-subject factor. The results showed that there was no main effect of Rate on reaction time (F (1, 19) < 1.00, p > .10). An ANOVA with Set Position (1-9) (sentence sets 1 through 9) as a within-subject factor indicated that reaction times also generally remained constant from set to set (F (8, 152) < 1.00, p > .10). A similar analysis was conducted on the subset of participants who showed adaptation in the first Compressed Rate block. The results revealed that their reaction times did not decrease as they adjusted to the compressed rate (F (2, 24) = 1.86, p > .10). This ruled out the possibility that the adaptation process also involves an increase in processing speed. Although the older group exhibited a slightly longer mean reaction time, an unpaired *t* test showed that the age difference was not reliable (t (18) = .92, p > .10). Since response latency did not vary by age, speech rate, or set position, reaction times were collapsed across these variables to obtain a mean reaction time for each participant.

In order to examine the relationship between speed of information processing (as measured by response latency) and word recall performance, participants were divided into a fast responder group (mean reaction times less than 1.00 s, N = 10) and a slow responder group (mean reaction times equal to or greater than 1.00 s, N = 10). An ANOVA was conducted with Rate (compressed vs. normal) as a within-subject factor and Response Latency (fast vs. slow) as a between-subject factor. As shown in Figure 6, the main effect of Response Latency and its interaction with Rate were marginally significant (F (1,18) = 3.73, p = .07 and F (1, 18) = 3.81, p = .07, respectively). Fast responders performed better than slow responders in the sentence recall

task, particularly at the compressed rate. Participants with faster reaction times recalled a mean of 87.5% of the words of the sentences while their slower counterparts recalled a mean of 79.6%.

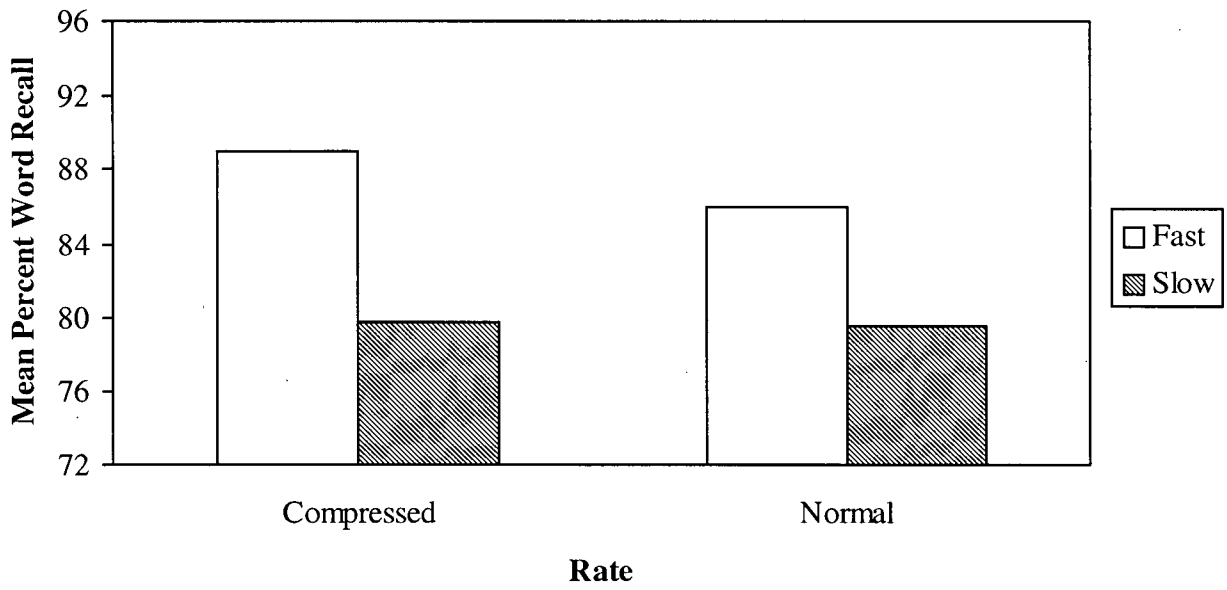

Figure 6. Mean word recall by rate for fast and slow responders.

These ANOVA findings, which suggest a relationship between response latency and word recall accuracy, were substantiated by correlation analysis. As shown in Table 4, the correlation between mean reaction times and recall accuracy was –.65 (p = .002). A stepwise regression analysis (which included the variables of listening span, digit span, gap detection thresholds, and reaction time) found reaction time, as a measure of speed of processing, to be the best predictor of overall recall performance, followed by digit span (see Table 5). Reaction times were also significantly correlated with scores on the listening span test (r = -.52, p = .02) but not with scores on the digit span test (r = -.02, p > .10), as shown in Table 4.

VARIABLE	R^2	B	SE B	β
Step 1				
Reaction time	.43	-9.61	2.71	-.65
Step 2				
Reaction time		-9.49	2.06	-.64
Digit span	.69	4.24	1.16	.51

Table 5. Summary of stepwise regression analysis for variables predicted to covary with word recall performance. Listening span and gap detection thresholds were variables not in the model.

4. CHAPTER FOUR: DISCUSSION

4.1 Discussion

Comprehension of spoken language is a complex behaviour which involves perception of the sound signal, extraction of relevant information, and integration of current information with recently processed input. When speech rate is increased, the signal is altered such that temporal acoustic cues become distorted and linguistic operations must be executed more rapidly in order to keep up with the accelerated rate of input. Consequently, the task of comprehension becomes a more effortful one.

The present study examined the comprehension of rapid speech by younger and older listeners after various amounts of exposure to time-compressed sentences. In the following section, the experimental findings will be discussed in relation to each of the research hypotheses outlined in Chapter One.

4.1.1 A Trade-Off Relationship Between Input Rate and Input Duration

Hypothesis 1. It was hypothesized that recall performance for both age groups would be poorer at the compressed rate than at the normal rate. Time-compression of speech stimuli exacerbates processing demands and has a detrimental effect on recall performance.

The results do not support the research hypothesis. Overall recall performance was better, though not significantly, at the accelerated rate than at the normal rate, which indicates that time-compression had the opposite effect of facilitating sentence recall. These findings are consistent with those of Schmitt and his colleagues, who demonstrated that slower-than-normal speech

rates do not substantially facilitate passage comprehension for older listeners (Schmitt, 1983; Schmitt & Carroll, 1985; Schmitt & Moore, 1989). In one study, they also found that compression of sentence stimuli enhanced comprehension performance rather than impairing it (Schmitt & McCroskey, 1981).

A plausible explanation for these findings lies in the notion of a trade-off relationship between input rate and input duration. When speech is time-compressed, the flow of incoming information proceeds at a faster rate. Assuming that one can cope with the rapid input rate, time-compression of a stimulus can facilitate comprehension by decreasing stimulus duration and therefore the amount of decay. For example, a compression rate of 68% in the present study means that compressed sentences occurred in 32% less time than uncompressed sentences. Because compressed sentences occurred in less time, less of the information that occurred earlier in the sentences was subject to decay, resulting in better recall. Conversely, time-expansion of speech slows down the input rate such that the same message occurs over a longer period of time. Consequently, more information may be lost from working memory through decay, making recall more difficult. This trade-off relationship may be particularly relevant when sentence stimuli are long, as in the present study. Acceleration of speech rate (i.e. reducing the duration of these long sentences) may have improved performance by facilitating the maintenance and integration of elements across the whole sentence. However, it is likely that there exists an upper-limit in the benefits of fast speech beyond which processing demands exceed perceptual and cognitive processing capabilities.

Another way to explain the relationship between input rate and input duration is in terms of a trade-off between speech rate and demands placed on working memory. When speech is slowed down, more processing time is available but information needs to be held in working

memory over a longer period of time. That is, the slower the speech rate, the more demands are placed on working memory and vice versa. This trade-off relationship is a likely explanation for the findings of Small and his colleagues (Small, Andersen, & Kempler, 1997; Small, Kemper, & Lyons, 1997). Similar to the older participants in Schmitt's studies, Alzheimer's disease patients in Small, Kemper, and Lyons's (1997) study did not benefit from a slower-than-normal rate. When speech is slowed down, the advantages of additional processing time may be counteracted by an accompanying increase in demands on working memory. Moreover, the results of the Small, Andersen, and Kempler (1997) study indicate that the effect of speech rate reduction on comprehension is dependent upon working memory capacity. A slower-than-normal speech rate adversely affected the comprehension of the AD patient with the most severe working memory impairment but had a beneficial effect on the performance of the patient with a relatively well-preserved working memory.

4.1.2 Age Differences in the Recall of Compressed Sentences

Hypothesis 2. It was hypothesized the recall performance of older participants would be poorer than that of younger participants at the compressed rate. Compression of speech material has been shown to affect older listeners' comprehension and memory for speech more than that of younger listeners due to age-related decrements in temporal processing, speed of processing, and/or working memory capacity.

The results revealed that, although the older group scored lower than the younger group on the compressed stimuli, this difference did not reach statistical significance. Successful recall of compressed speech requires intact auditory functioning, an ability to process rapid input, and a sufficient working memory capacity for simultaneous storage and manipulation of information.

Age-related deficits in temporal processing (Fitzgibbons & Gordon-Salant, 1996; Schneider et al., 1994; Schneider & Pichora-Fuller, 2000), working memory capacity (Just & Carpenter, 1992; Light & Anderson, 1985; Norman et al., 1992; Stine and Wingfield, 1987), and speed of information processing (Birren et al., 1980; Salthouse & Babcock, 1991; Verhaeghen & Salthouse, 1997) may impair older adults' ability to process fast speech.

The lack of a reliable age difference in recall performance at the compressed rate could be attributed in part to the fact that sentence stimuli were accelerated to a lesser degree than in previous research. Wingfield and his colleagues have used markedly higher compression rates, resulting in faster-than-normal speech rates of 300 wpm and beyond. At these extremely fast rates, both younger and older adults recalled fewer words than at the normal rate, presumably due to the heavy processing load. However, relative to the younger adults, performance of the older participants showed a disproportionate decline with an increase in speech rate (e.g. Stine et al., 1986; Wingfield et al, 1985). Such age-related deficits in language performance have been found to be especially evident when processing demands are high. For instance, factors such as competing background noise (Pichora-Fuller et al., 1995; Tun, 1998) and complex syntax (Kemper, 1986, 1997; Norman et al., 1992) place a strain on the diminished processing capacity of older adults, thereby affecting their listening comprehension.

In the present study, a lower rate of compression was employed in order to allow recall accuracy at the compressed rate to improve to normal rate performance levels (based on pilot data). A compression rate of 68% was used, resulting in sentences being presented at a moderately fast rate of 265 wpm. Although the pilot results showed poorer recall for this compressed rate than the uncompressed rate, this pattern of results was not present in the larger study. The latter findings indicate that a moderate acceleration of input rate may not exacerbate

processing demands to the extent of compromising recall performance. Time compression of speech had no effect on older listeners' performance. On the contrary, the faster rate facilitated recall for younger listeners (although not significantly), which suggests a trade-off between speech rate and sentence length as discussed previously.

Although some findings of the present study were not statistically significant (possibly due to the small sample), they do suggest a trend in which a relatively slower rate of speaking may not necessarily enhance comprehension but instead impair it, particularly when utterances are long. Thus, there appears to be a trade-off between input rate and input duration such that as speech rate decreases, more demands are placed on working memory, whereas moderate increases in rate may lead to better performance. These findings suggest that the efficacy of using a slow speech rate to accommodate age-related cognitive limitations may be questionable. Elderspeak, the speech register targeted at older adults, is characterized by the use of a slower speech rate, in addition to shortened utterances, simplified syntax and vocabulary, high pitch, and exaggerated prosody.

Although elderspeak is intended to accommodate to the cognitive limitations of older adults by decreasing processing demands, its use may not benefit older communicative partners and may actually be detrimental to self-assessments of their own communicative competence. Kemper, Othick, Gerhing, Gubarchuk, and Billington (1998) found that with practice, young adults' instructions to older listeners during a referential communication task became more repetitious, shorter, simpler, and slower. These speech accommodations triggered negative self-evaluations of communicative competence by the older listeners but did not enhance their performance on the task. That is, the use of slower and simpler speech appeared to elicit older adults' perceptions of themselves as communicatively impaired. Clearly, the benefits and costs

of using a slower speech rate and/or other speech modifications must be considered in communicative interactions with older adults.

4.1.3 Adaptation to Compressed Speech

Hypothesis 3. It was hypothesized that recall of compressed sentences would increase through practice for both younger and older participants. Such an improvement would provide evidence that experience with compressed speech results in perceptual adaptation.

The results provide some evidence of adaptation to compressed speech in that 13 of the 20 participants showed improvement in their performance over time. The most plausible explanation for this outcome is that a subset of participants performed near ceiling due to the moderate rate of compression, thus leaving little room for improvement. Dupoux and Green (1997) found adaptation effects at high compression rates of 38% and 45%. At 38% compression (approximately 475 wpm), participants in that study achieved initial word recall scores of only 30%. Over the course of adaptation to the compressed sentences, their performance improved by 10%. At 45% compression (approximately 400 wpm), recall scores increased from 65% to 77%.

In the present study, sentences were compressed by 68%, resulting in a moderately fast speech rate of 265 wpm. An examination of recall performance in the first Compressed Rate block revealed that participants who adapted to the compressed rate began at a recall accuracy of 79% in Set 1, which increased to 82.5% in Set 2, and peaked at 85% in Set 3. In contrast, participants who did not show adaptation to the compressed rate achieved a mean recall score of 89% in Set 1, after which their performance declined. These participants performed near ceiling at the outset of the experiment, leaving no room for improvement with increased exposure to the

compressed rate. That is, recall scores did not increase to the level observed at the normal rate in previous research (i.e. around 95%) as was predicted. Due to the constraints of a finite working memory capacity, the length of the sentence stimuli (16 to 18 words) may have produced an upper limit in recall performance such that non-adapting participants performing near this limit did not have a chance to adapt to the compressed rate.

Interestingly, participants who showed adaptation to compressed speech obtained lower overall word recall scores, listening span scores, and digit span scores than those who did not show adaptation, although none of these group differences reached statistical significance. This suggests that the degree of adaptation to compressed speech may be mediated by individual differences in working memory capacity. That is, higher-capacity individuals who are relatively more skilled at processing rapid speech may have less to gain from exposure to compressed input than lower-capacity individuals.

4.1.4 Age Differences in Adaptation to Compressed Speech

Hypothesis 4. It was hypothesized that older participants would show a slower rate of improvement in recall than younger participants due to the effects of cognitive slowing. That is, older listeners' performance would take longer to reach asymptote than that of younger listeners.

Hypothesis 5. It was hypothesized that older participants would show less improvement with practice than younger participants. Comprehension of compressed speech involves processing of complex perceptual information. It is likely, then, that age-related deficits in temporal processing would limit the extent to which older listeners could adjust to compressed speech.

Although younger and older participants (whose performance improved over time) demonstrated different patterns of adaptation, the statistical results indicated that the Set Position X Age interaction was not statistically significant. This was most likely due to the small sample size. Nevertheless, the pattern of results tend to suggest that the performance of the younger group improved at a faster rate and to a greater extent than that of the older group.

The older participants' slower rate of improvement was predicted based on previous findings of cognitive slowing in later adulthood (Birren et al., 1980; Salthouse & Babcock, 1991; Verhaeghen & Salthouse, 1997). Age-related slowing of cognitive operations may result in a slower rate of perceptual skill learning in older adults such that they would require more exposure to compressed speech before attaining maximum adjustment. In the present study, recall accuracy of the younger group improved by about 4% with each set of compressed sentences while that of the older group increased by only 2% with each set. The performance of younger participants dropped in Set 7 (the second Compressed Rate block) while older participants continued to improve by another 2%. This pattern of findings, while not statistically significant, suggests that younger participants reached a plateau in recall performance within the first block of compressed sentences while older participants continued to adapt into the second block of compressed sentences. The older group's slower adaptation to the compressed speech suggests that age-related slowing of cognitive operations may have affected their rate of learning.

Because comprehension of compressed speech involves processing of complex perceptual information, it was also predicted that age-related deficits in temporal processing would limit the extent to which older adults could adjust to an accelerated speech rate. In accordance with this prediction, the results revealed that while performance of the younger group improved by 8% over the course of exposure to compressed speech, recall accuracy of the older

group only increased by 6%. The older group also demonstrated poorer temporal acuity, as shown by their increased thresholds on the gap detection test.

4.1.5 The Effect of a Change in Compression Rate on the Adaptation Process

Hypothesis 6. It was hypothesized that during the adaptation process, a sudden change to uncompressed speech would only result in a slight decline in recall scores immediately following the change, after which performance would return to the previous adapted level. Such a recovery would provide evidence that perceptual adjustment to compressed speech is related to perceptual learning.

In contrast to what was observed in Dupoux and Green (1997), the results of this study showed no drop in performance on compressed sentences immediately following an interval of uncompressed sentences. Dupoux and Green (1997) had attributed the slight decrement in performance (from compressed → uncompressed → compressed) in their study to rate normalization processes associated with perceptual readjustment to the compressed rate. Previous findings suggest that variation in speech rate results in spectral changes and that the listener accommodates to these changes by processing temporal cues in relation to the rate of speech at which they were produced (Miller, 1981; Miller & Liberman, 1979). An immediate drop in performance following the switch to a compressed rate from an uncompressed rate may reflect such rate normalization processes, which occur automatically in response to local variations in the speech signal. The fact that the performance drop in Dupoux and Green's (1997) study was temporary suggests that adaptation to accelerated speech reflects a perceptual learning process.

The absence of a temporary drop in performance in the present study could be due to the moderate compression rate. Perhaps because sentences were compressed to a lesser degree in the present study, the interval of uncompressed sentences did not present as dramatic a change in speech rate as in Dupoux & Green (1997). The latter study involved a change from 38% rate compression (475 wpm) to 0% rate compression (normal rate of 180 wpm) and back to 38% rate compression (475 wpm). The present experiment involved a switch from 68% rate compression (265 wpm) to 0% (180 wpm) and back to 68% (265 wpm). Perhaps this change in speech rate was too small to have a significant impact on rate normalization processes in the perceptual system. Consistent with this explanation, Dupoux and Green (1997) found that switching from 38% compressed speech (475 wpm) to 50% compressed speech (360 wpm) did not result in a significant decrease in performance upon returning to the 38% compression rate (475 wpm).

Although there was no decline in performance following a rate change in this study, contrary to what was predicted, the results do indicate that the increase in performance which occurred over the course of the first 15 compressed sentences was maintained despite the intervening block of uncompressed sentences. Comparable to the findings of Dupoux and Green (1997), this indicates that adaptation to compressed speech does not merely reflect short-term adjustments in the form of normalization processes but rather it involves a perceptual learning process.

4.1.6 Factors Associated with Recall Performance

4.1.6.1 Temporal Processing Ability, as Measured by the Gap Detection Test

Hypothesis 7. It was hypothesized that there would be a negative correlation between gap detection thresholds and recall performance at the compressed rate but not at the

normal rate. Temporal processing ability affects speech perception, especially when temporal acoustic cues are distorted due to time-compression of the signal.

As predicted, the results showed a negative correlation between gap detection thresholds and recall performance at the compressed rate but not at the normal rate. At the compressed rate, participants with a low gap detection threshold performed better than those with a high threshold while there was no difference in performance at the normal rate. Time-compression of speech results in distortion of low-level temporal acoustic cues (e.g., VOT, transition duration) in the signal. Acceleration of speech rate also reduces acoustic cues to extremely brief durations which are likely to be difficult for the perceptual system to interpret. Thus, auditory temporal processing ability is an important factor in the comprehension and recall of compressed sentences.

Consistent with the findings of Schneider et al. (1994), the older group had significantly higher gap detection thresholds than the younger group. Older listeners, who have been shown to have deficits in temporal resolving ability (Fitzgibbons & Gordon-Salant, 1996; Gordon-Salant & Fitzgibbons, 1993; Schneider & Pichora-Fuller, 2000), also performed more poorly than younger listeners at the compressed rate, though the difference was not statistically significant. Thus, aging seems to affect the ability to detect the rapid and impoverished acoustic cues present in time-compressed speech, resulting in poorer recall performance.

4.1.6.2 Working Memory Capacity, as Measured by the Listening Span and Digit Span Tests

Hypothesis 8. It was hypothesized that there would be a positive correlation between measures of working memory and recall performance. Working memory plays an important

role in listening comprehension, which requires simultaneous processing and storage of information.

The listening span task and digits backward span task were used to assess working memory capacity. Scores on both measures were found to be positively correlated with sentence recall performance. Participants with higher working memory spans performed better than those with lower spans.

Potter and Lombardi (1990) found that, in immediate sentence recall, the listener forms a representation of the sentence's meaning as it is being heard, and then reconstructs the surface form based on this conceptual representation, using recently activated lexical items. In other words, the correct recall of a spoken sentence entails extracting and maintaining words from the transient acoustic signal and integrating them in order to form a meaningful interpretation of the sentence. Thus, speech comprehension involves the ability to manipulate and hold information over time (Daneman & Carpenter, 1980). Consistent with previous findings of an age-related reduction in working memory capacity (Just & Carpenter, 1992; Light & Anderson, 1985; Norman et al., 1992; Stine and Wingfield, 1987), older participants scored lower than younger participants on the listening span test. However, the age difference on the digit span test did not reach statistical significance. This may be due to task-related differences between the two measures. The listening span task requires sentence interpretation (for making semantic plausibility judgements) whereas the digit span test does not. The results of Daneman and Merikle's (1996) meta-analysis indicated that measures which tap verbal processes are the best predictors of comprehension performance.

4.1.6.3 Speed of Processing, as Measured by Response Latency on the Sentence Recall Task

Hypothesis 9. It was hypothesized that there would be a negative correlation between reaction time (as a measure of speed of processing) and recall performance. Speed of information processing is an important factor in listening comprehension because the listener must keep up with the continuous flow of information in the speech stream.

Reaction time was found to be highly correlated with word recall performance such that fast responders performed better than slow responders, particularly at the compressed rate. A stepwise regression equation found reaction time to be the best predictor of recall success compared to gap detection thresholds, digit span, and listening span. This suggests that speed of processing is a critical factor in listening comprehension. Slow responders are most likely poorer or less efficient at processing incoming information. Consequently, their rate of processing may fall behind the decay rate such that some prior information may already have decayed by the time more recent information is processed. Because sentence-initial elements may not be available in working memory for integration with items occurring later in the sentence, recall performance would be affected. Conversely, it is likely that fast responders are more adept at recalling spoken sentences because they are inherently better at processing information. This is also a plausible explanation for the positive correlation between listening span scores and response latency. Participants who are faster at processing information are more likely to process sentences in the listening span test at a rate which allows the optimum number of sentence-final words to be held in working memory for recall.

The difference in performance between fast responders and slow responders on the sentence recall task was greater at the compressed rate, compared to the normal rate. When speech is time-compressed, more information must be processed in less time. Individuals who

are faster at processing information are likely better able to cope with the accelerated input rate than those who are slower. For the latter group, speed of processing may fall below the rate of input and result in insufficient processing of incoming information.

An alternative explanation is that fast responders performed better in the sentence recall task because they did not spend as much time processing the meaning of the sentences as slow responders. If it were true that fast responders merely repeated the surface string of words in sentences without processing their meaning, then they should have exhibited poorer recall of propositions. To test this possibility, an unpaired t test was conducted on propositional recall data. The results showed that fast responders were also better than slow responders at recalling propositions, indicating that fast responders did indeed process the sentences beyond the surface representation of the words. Furthermore, participants' responses contained a considerable amount of paraphrasing and word substitutions, suggesting that sentences were processed for meaning. Similarly, Wingfield et al. (1995) found that even when immediate recall is not perfectly accurate, responses tend to remain semantically coherent and contain reconstructions of the original utterance.

These findings are compatible with Potter and Lombardi's (1990) hypothesis that, in immediate sentence recall, the listener forms a representation of the sentence's meaning as it is being heard, and then reconstructs the surface form based on this conceptual representation, using recently activated lexical items. Potter and Lombardi (1998) found that, in addition to lexical activation, syntactic priming also plays a role in immediate sentence recall. When a sentence is regenerated from its meaning, the most recently activated syntactic structure has the highest likelihood of being reproduced in recall. This contributes to the verbatim nature of

immediate sentence recall in that the most recently activated structure is normally that of the target sentence itself.

Thus in recalling a sentence, the most recently activated lexical and syntactic forms tend to be used to reconstruct the surface form of the sentence. According to Potter and Lombardi (1998), the amount of activated information available for use in immediate verbatim recall may be subject to rapid decay because it is less distinctive than conceptual information. They explain that information may only be active for a short time in "verbatim" memory since the listener's goal is typically "to extract and encode meaning, discarding the lexical and syntactic forms that convey the meaning" (p. 277). It is reasonable to assume that the recall performance of slow responders in the present study may have been especially susceptible to this rapid decay rate. They required more time to process the meaning of the sentences, thereby allowing a higher number of activated elements to be lost through decay.

4.2 Concluding Remarks

The present study explored age differences in adaptation to fast speech using a sentence recall task. In view of known decrements in temporal processing, working memory capacity, and processing speed with age, older adults were expected to perform more poorly than younger adults at the accelerated speech rate. However, the results revealed no age differences in performance, perhaps due to the moderate degree to which sentences were compressed. Rather than impairing recall as predicted, moderate acceleration of speech rate had no effect on the performance of older listeners and slightly enhanced that of younger listeners. This provides support for the caution that speech accommodations to older listeners, such as the use of a slower speech rate, may not be necessary. On the other hand, there were significant correlations between

word recall performance and gap detection thresholds, working memory scores, and response latency. This suggests that temporal processing ability, working memory capacity, and speed of processing play a critical role in the comprehension of spoken language.

Theoretically, perceptual adaptation to compressed speech is a phenomenon which raises interesting questions about spoken language processing and the effects of practice. For instance, what are the underlying mechanisms of compression adjustment? One hypothesis is that practice in processing rapid input leads to more efficient processing or a higher speed of processing. This, however, was not supported in that the improvement in performance among those participants who showed adaptation was not accompanied by a decrease in response latency. On the other hand, results showing improvement in older (adapting) participants' performance indicate that training in recalling compressed stimuli may reduce the demands of processing fast speech and ease the burden on individuals with limited resource capacities. In other words, repeated exposure to temporally distorted input can lead to a reduction in the amount of processing resources required for perceptual processing, thus freeing up resources for cognitive functions such as retrieval of stored information. It would be interesting to examine the effect of practice on listening comprehension in other perceptually demanding conditions such as noisy or reverberant environments.

The experiment reported here involved a small sample of individuals and the results offered preliminary evidence of adaptation to accelerated speech. Consistent with the findings of Dupoux and Green (1997), participants who demonstrated adaptation did not return to their original unadapted performance level after they were presented with uncompressed speech. This indicates that improvement in performance over the course of exposure to rapid input may reflect a learning process. As predicted, older adults appeared to adapt at a slower rate and to a lesser

extent than younger adults although interaction effects were not statistically significant. It is possible that, with a larger sample, more robust findings would be obtained which would further elucidate the relationship between age and compression adjustment, thereby shedding light on the plasticity of language processing ability throughout the lifespan.

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APPENDIX A

Shipley (1940) Vocabulary Test

NAME_____

In the test below, the first word of each line is printed in CAPITAL LETTERS. Opposite it are four other words. Circle the one word which means the same thing, or most nearly the same thing, as the first word. A sample has been worked out for you. If you don't know, guess. Be sure to circle the one word in each line which means the same thing as the first word.

sample

LARGE	red	big	silent	wet
1. TALK	draw	eat	speak	sleep
2. PERMIT	allow	sew	cut	drive
3. PARDON	forgive	pound	divide	tell
4. COUCH	pin	eraser	sofa	glass
5. REMEMBER	swim	recall	number	defy
6. TUMBLE	drink	dress	fall	think
7. HIDEOUS	silvery	tilted	young	dreadful
8. CORDIAL	swift	muddy	leafy	hearty
9. EVIDENT	green	obvious	skeptical	afraid
10. IMPOSTER	conductor	officer	book	pretender
11. MERIT	deserve	distrust	fight	separate
12. FASCINATE	welcome	fix	stir	enchant
13. INDICATE	defy	excite	signify	bicker
14. IGNORANT	red	sharp	uninformed	precise
15. FORTIFY	submerge	strengthen	vent	deaden
16. RENOWN	length	head	fame	loyalty
17. NARRATE	yield	buy	associate	tell

18.	MASSIVE	bright	large	speedy	low
19.	HILARITY	laughter	speed	grace	malice
20.	SMIRCHED	stolen	pointed	remade	soiled
21.	SQUANDER	tease	belittle	cut	waste
22.	CAPTION	drum	ballast	heading	ape
23.	FACILITATE	help	turn	strip	bewilder
24.	JOCOSE	humorous	paltry	fervid	plain
25.	APPRISE	reduce	screw	inform	delight
26.	RUE	eat	lament	dominate	cure
27.	DENIZEN	senator	inhabitant	fish	atom
28.	DIVEST	dispossess	intrude	rally	pledge
29.	AMULET	charm	orphan	dingo	pond
30.	INEXORABLE	untidy	involatile	rigid	sparse
31.	SERRATED	dried	notched	armed	blunt
32.	LISSOM	moldy	loose	supple	convex
33.	MOLLIFY	mitigate	direct	pertain	abuse
34.	PLAGIARIZE	misappropriate	intend	revoke	maintain
35.	ORIFICE	brush	hole	building	lute
36.	QUERULOUS	maniacal	curious	devote	complaining
37.	PARIAH	outcast	priest	lentil	locker
38.	ABET	waken	ensue	incite	placate
39.	TEMERITY	rashness	timidity	desire	kindness
40.	PRISTINE	vain	sound	first	level

APPENDIX B

Background Characteristics of Individual Participants

Participant	Sex	Age	Years of Education	Vocabulary Score (% correct)
O-1	M	67	16	95
O-2	F	77	12	95
O-3	F	65	16	98
O-4	M	69	12	90
O-5	F	62	12	70
O-6	F	78	14	98
O-7	M	74	16	90
O-8	M	73	12	92
O-9	F	72	15	95
O-10	M	67	18	98
Y-1	F	20	14	68
Y-2	M	30	16	88
Y-3	F	20	15	78
Y-4	F	20	15	82
Y-5	F	21	15	57
Y-6	F	22	17	82
Y-7	F	21	16	85
Y-8	M	23	16	80
Y-9	F	21	15	85
Y-10	M	25	19	80

Note. O = Old and Y = Young.

APPENDIX C

Name: _____ Subject #: _____

Gender: ___M ___F Date of Birth: ___/___/___ Age: _____

Date of Testing: _____

Address: _____

_____

Home Phone #: _____ Work #: _____

May we contact you about participating in other studies in the future?

___Yes ___No

What is your first language? _____

Do you speak any other language(s) fluently?_____

Are you right- or left-handed? ____Right ___Left

Have you ever changed the hand that you prefer to write with?

___Yes ___No

If yes, why? _____

Education: _____

(in total years – e.g. 8 = grade school, 12 = high school, 16 = bachelors degree, 18 = master's degree, 22 = Ph.D degree)

Do you have any trouble with your vision? ___Yes ___No

What kind? _____

Do people ever complain about your hearing? ___Yes ___No

Have you ever had a hearing test? ___Yes ___No

Do you wear a hearing aid? ___Yes ___No

Do you regularly take any medication? ___Yes ___No

What kind? _____

Have you ever had any of the following conditions?:

_____ Accident involving a head injury

_____ Heart attack

_____ Stroke or TIA

_____ Unusual memory problems

_____ Any other serious health problems

What kind? _____

_____

_____

APPENDIX D

Pure-Tone Air-Conduction Thresholds and Speech Reception Thresholds of Individual Participants

Participant	RIGHT EAR							
	Frequency (kHz)							SRT
	.25	.5	1	2	3	4	8	
O-1	10	10	20	20	25	35	70	20
O-2	15	15	5	20	25	40	80	15
O-3	10	10	5	5	-5	15	20	0
O-4	5	10	15	0	15	25	30	0
O-5	5	5	15	15	15	5	25	5
O-6	30	25	25	20	15	30	45	20
O-7	5	0	5	5	5	20	65	5
O-8	15	10	10	15	15	60	45	5
O-9	15	10	10	5	5	5	30	0
O-10	5	0	10	0	15	40	25	5
Y-1	10	10	5	0	10	0	5	5
Y-2	10	5	5	-5	0	0	5	-5
Y-3	0	0	-5	-10	-5	-10	-10	-5
Y-4	15	5	5	-5	0	-5	5	0
Y-5	25	25	15	10	5	5	5	0
Y-6	0	5	5	-5	5	5	-5	-5
Y-7	5	5	5	5	10	0	0	0
Y-8	5	5	0	0	5	0	0	-5
Y-9	10	10	10	5	10	5	5	-5
Y-10	5	0	0	0	-5	-5	5	-10

Note. All threshold values are expressed in dB HL. O = Old and Y = Young.
SRT = Speech Reception Threshold.

Participant	LEFT EAR							
	Frequency (kHz)							SRT
	.25	.5	1	2	3	4	8	
O-1	5	5	15	20	25	40	60	15
O-2	15	10	10	20	25	35	80	5
O-3	10	10	0	0	0	5	25	0
O-4	35	30	15	5	15	20	60	5
O-5	15	5	0	5	15	10	30	5
O-6	20	20	20	10	20	15	30	15
O-7	15	5	5	5	5	25	65	5
O-8	15	15	5	0	15	45	45	10
O-9	10	5	5	0	5	10	35	5
O-10	10	0	0	0	10	20	15	0
Y-1	10	5	5	5	5	0	0	0
Y-2	10	5	10	10	0	5	10	5
Y-3	0	0	0	-5	0	-5	5	0
Y-4	10	0	10	5	0	15	5	0
Y-5	15	10	0	0	5	10	0	-5
Y-6	0	0	0	5	-5	5	0	-5
Y-7	5	5	-5	20	25	5	25	10
Y-8	5	5	0	0	0	-5	0	-5
Y-9	10	10	10	10	5	0	5	5
Y-10	0	0	-5	0	-5	-10	5	-5

Note. All threshold values are expressed in dB HL. O = Old and Y = Young.
SRT = Speech Reception Threshold.

APPENDIX E

Sentence Recall Stimuli and Propositional Representations

1. When some friends invited the lonely girl to their summer cottage by the lake, she became very excited.

1. (friends, some)
2. (girl, lonely)
3. (cottage, summer)
4. (cottage, their)
5. (by, cottage, lake)
6. (to, cottage)
7. (excited, very)
8. (invited, 1, 2)
9. (became, she, 7)
10. (when, 8, 9)

2. Unless the reckless driver slows down, he will hit the cement truck turning left at the next intersection.

1. (driver, reckless)
2. (truck, cement)
3. (turning, truck)
4. (turning, left)
5. (at, intersection)
6. (intersection, next)
7. (slows down, driver)
8. (hit, he, truck)
9. (unless, 7, 8)

3. The desperate man applied for the temporary sales position since there were no other jobs available.

1. (man, desperate)
2. (position, sales)
3. (position, temporary)
4. (jobs, other)
5. (jobs, no)
6. (jobs, available)
7. (were, there, 5)
8. (applied, man)
9. (for, position)

10. (since, 7, 8)

4. The dining table was cleared soon after dinner so that the children could finish their science project.

1. (table, dining)
2. (project, science)
3. (project, their)
4. (after, soon)
5. (after, dinner)
6. (finish, children, 2)
7. (cleared, x, 1)
8. (so that, 7, 6)

5. Performing on stage has been the singer's dream since she attended her first concert as a small child.

1. (dream, singer's)
2. (concert, first)
3. (concert, her)
4. (child, small)
5. (on, stage)
6. (perform, singer, 5)
7. (be, 1, 6)
8. (attended, she, 2)
9. (as, 8, 4)
10. (since, 8, 7)

6. How the abandoned animal managed to find its way back to the farm is difficult to explain.

1. (animal, abandoned)
2. (to, farm)
3. (way, back)
4. (way, its)
5. (find, animal, 4)
6. (managed, animal, 5)
7. (6, how)
8. (explain, x, 7)
9. (is, 8, difficult)

7. Where the rebellious teenager hid the pack of cigarettes during math class is easy to guess.

1. (teenager, rebellious)
2. (of, cigarettes)
3. (class, math)
4. (hid, teenager, pack)

5. (4, where)
6. (during, class)
7. (guess, x, 5)
8. (is, 7, easy)

8. The devoted hockey fan listened anxiously to the radio to find out which team was in the lead.

1. (fan, hockey)
2. (fan, devoted)
3. (team, which)
4. (to, radio)
5. (listened, fan, 4)
6. (listened, anxiously)
7. (in, 3, lead)
8. (was, 3, 7)
9. (find out, fan, 8)

9. The person at the information booth showed us where we could purchase tickets for the amusement park rides.

1. (booth, information)
2. (park, amusement)
3. (rides, 2)
4. (at, person, 1)
5. (for, 3)
6. (purchase, we, tickets)
7. (6, where)
8. (showed, 4, us, 7)

10. The hero who rescued a frightened cat from a burning trailer accepted many gifts from its grateful owner.

1. (cat, frightened)
2. (trailing, burning)
3. (from, trailer)
4. (owner, grateful)
5. (from, owner)
6. (rescued, hero, cat)
7. (gifts, many)
8. (accepted, hero, 7, 5)

11. The athlete who won the gold medal in the local skating competition stood proudly on the tall podium.

1. (medal, gold)
2. (competition, skating)

3. (2, local)
4. (on, podium)
5. (podium, tall)
6. (stood, athlete)
7. (6, proudly)
8. (won, athlete, 1)
9. (in, competition)

12. The clowns that the children saw at the circus last night performed silly magic tricks with colourful scarves.

1. (night, last)
2. (tricks, magic)
3. (tricks, silly)
4. (scarves, colourful)
5. (with, 8, scarves)
6. (at, circus)
7. (saw, children, clowns)
8. (performed, clowns, tricks)

13. News reporters interviewed the famous author who writes fascinating books about growing up during the war.

1. (reporters, news)
2. (author, famous)
3. (books, fascinating)
4. (during, war)
5. (grow up, author)
6. (about, 5)
7. (writes, author, books)
8. (interviewed, 1, 2)

14. The proud father admired a necklace that his daughter had skillfully made using string and dried apple seeds.

1. (father, proud)
2. (daughter, his)
3. (seeds, apple)
4. (seeds, dried)
5. (and, 3, string)
6. (using, daughter, 5)
7. (made, daughter, necklace)
8. (7, skillfully)
9. (admired, father, necklace)

15. The thrifty shopper later returned the plastic cups that she had bought hastily at the discount store.

1. (shopper, thrifty)
2. (cups, plastic)
3. (store, discount)
4. (at, store)
5. (bought, she, cups)
6. (5, hastily)
7. (returned, shopper, cups)
8. (7, later)

16. Though it only takes several minutes, my lazy neighbor dreads raking the leaves in the yard each autumn.

1. (minutes, several)
2. (neighbor, lazy)
3. (neighbor, my)
4. (autumn, each)
5. (takes, it, 1)
6. (5, only)
7. (raking, neighbor, leaves)
8. (dreads, neighbor, 7)
9. (in, leaves, yard)
10. (though, 6, 8)

17. Although the tourist had a detailed map, he could not find the main entrance to the national park.

1. (park, national)
2. (entrance, main)
3. (to, park)
4. (map, detailed)
5. (find, he, entrance)
6. (find, not)
7. (had, tourist, map)
8. (although, 7, 5)

18. My sister avoids eating meat and dairy products because she is on a strict vegetarian diet.

1. (sister, my)
2. (products, dairy)
3. (diet, vegetarian)
4. (diet, strict)
5. (on, she, diet)
6. (and, meat, 2)

7. (eat, 1, 6)
8. (avoids, 1, 7)
9. (because, 5, 8)

19. The curious children stared at the massive dinosaur exhibits when they visited the museum this week.

1. (children, curious)
2. (exhibits, dinosaur)
3. (exhibits, massive)
4. (week, this)
5. (at, exhibits)
6. (stared, children)
7. (visited, they, museum)
8. (when, 7, 6)

20. Why the woman did not use her emergency brake puzzles onlookers at the scene of the crash.

1. (brake, emergency)
2. (brake, her)
3. (of, crash)
4. (at, scene)
5. (use, woman, brake)
6. (use, not)
7. (5, why)
8. (puzzles, 7, onlookers)

21. That a respected member of their society confessed to the crime shocked citizens in the quiet town.

1. (member, respected)
2. (of, society)
3. (society, their)
4. (town, quiet)
5. (to, crime)
6. (confessed, member, 5)
7. (in, citizens, town)
8. (shocked, 6, citizens)

22. That the large cosmetics company supports animal rights is good for its loyal customers to know.

1. (company, cosmetics)
2. (company, large)
3. (rights, animal)

4. (customers, loyal)
5. (customers, its)
6. (supports, 1, 3)
7. (know, 4, 6)
8. (is, 7, good)

23. This library book on the behaviour of birds describes how flocks of geese migrate south for the winter.

1. (book, library)
2. (book, this)
3. (on, behaviour)
4. (of, birds)
5. (of, geese)
6. (migrate, flocks)
7. (migrate, south)
8. (for, winter)
9. (6, how)
10. (describes, book, 9)

24. Police officers found the empty safe and concluded that robbery had indeed been the motive for the crime.

1. (officers, police)
2. (safe, empty)
3. (found, officers, 2)
4. (for, crime)
5. (be, robbery, motive)
6. (5, indeed)
7. (concluded, police, 5)
8. (and, 3, 7)

25. The soccer players who won the final match celebrated their victory by dancing in the streets until dawn.

1. (players, soccer)
2. (match, final)
3. (victory, their)
4. (in, players, streets)
5. (dancing, players)
6. (until, dawn)
7. (won, players, match)
8. (celebrated, players, 3)

26. The maid who frequently cleans our hotel room changes the sheets and leaves clean towels in the closet.

1. (room, hotel)
2. (room, our)
3. (towels, clean)
4. (in, towels, closet)
5. (cleans, maid, room)
6. (cleans, frequently)
7. (changes, maid, sheets)
8. (leaves, maid, 3)
9. (and, 7, 8)

27. The workers that they hired to handle major renovations first examined the damaged walls of the old house.

1. (house, old)
2. (of, house)
3. (walls, damaged)
4. (examined, workers, 3)
5. (examined, first)
6. (renovations, major)
7. (hired, they, workers)
8. (handle, workers, 6)

28. The noisy construction crew disturbed many elderly residents who lived across the street from the building site.

1. (crew, construction)
2. (1, noisy)
3. (residents, elderly)
4. (residents, many)
5. (across, street)
6. (site, building)
7. (from, site)
8. (disturbed, crew, residents)
9. (lived, residents, 5)

29. The politician strongly denied harsh accusations that people made about his affair with a young actress.

1. (accusations, harsh)
2. (affair, his)
3. (actress, young)
4. (with, actress)
5. (about, affair)
6. (made, people, accusations)
7. (denied, politician, 1)

8. (denied, strongly)

30. The forgetful student could not remember the simple instructions that her teacher gave for the math assignment.

1. (student, forgetful)
2. (instructions, simple)
3. (teacher, her)
4. (assignment, math)
5. (for, assignment)
6. (gave, teacher, 2)
7. (remember, student, 2)
8. (remember, not)

31. After wandering around the train station for hours, the homeless man was approached by a security guard.

1. (station, train)
2. (around, station)
3. (man, homeless)
4. (guard, security)
5. (wander, man)
6. (for, hours)
7. (wander, 6)
8. (approach, 4, 3)
9. (after, 5, 8)

32. Once the dentist explained the painless procedure to the nervous woman, she began to feel more at ease.

1. (procedure, painless)
2. (woman, nervous)
3. (feel, she, at ease)
4. (at ease, more)
5. (began, she, 3)
6. (explained, dentist, 1)
7. (to, woman)
8. (once, 6, 5)

33. The woman in the silver car gazed at the brilliant sunset as she drove across the long bridge.

1. (car, silver)
2. (sunset, brilliant)
3. (bridge, long)
4. (across, bridge)
5. (drove, she)
6. (in, woman, car)

7. (at, sunset)
8. (gazed, woman, 7)
9. (as, 5, 8)

34. The leak under the kitchen sink was not repaired until the angry tenants threatened to move out.

9. (sink, kitchen)
10. (tenants, angry)
11. (under, leak, sink)
12. (repaired, x, leak)
13. (repaired, not)
14. (move out, tenants)
15. (threatened, tenants, 6)
16. (until, 4, 7)

35. Exactly when the next earthquake will occur in this area is impossible for experts to predict.

1. (earthquake, next)
2. (area, this)
3. (in, area)
4. (for, experts)
5. (occur, 1)
6. (5, when)
7. (6, exactly)
8. (predict, experts, 7)
9. (is, 8, impossible)

36. That the crooked lawyer arrived late for the budget meeting hardly surprises the other committee members.

1. (lawyer, crooked)
2. (meeting, budget)
3. (members, committee)
4. (members, other)
5. (for, meeting)
6. (arrived, late)
7. (arrived, 1)
8. (surprises, hardly)
9. (surprises, 7, 3)

37. The courteous post office clerk figured out how much it would cost to ship my computer back home.

1. (office, post)
2. (clerk, courteous)

3. (clerk, 1)
4. (computer, my)
5. (back, home)
6. (ship, x, 4, 5)
7. (cost, it, how much)
8. (figured out, clerk, 7)

38. The young inexperienced driver did not realize that he had misread the sign and parked illegally.

1. (driver, inexperienced)
2. (driver, young)
3. (misread, he, sign)
4. (parked, driver)
5. (parked, illegally)
6. (and, 3, 4)
7. (realize, driver, 6)
8. (realize, not)

39. The frantic bride and groom cannot believe that the florist delivered the wedding bouquets to the wrong church.

1. (and, bride, groom)
2. (1, frantic)
3. (bouquets, wedding)
4. (church, wrong)
5. (to, church)
6. (deliver, florist, 3, 5)
7. (believe, 2, 6)
8. (believe, not)

40. Dedicated employees who work hard and make few mistakes will achieve great success at the company.

1. (employees, dedicated)
2. (mistakes, few)
3. (at, company)
4. (success, great)
5. (work, employees)
6. (work, hard)
7. (make, employees, 2)
8. (and, 5, 7)
9. (achieve, employees, success)

41. The movie that my brother saw recently at the local theatre inspired him to explore distant lands.

1. (brother, my)
2. (theatre, local)
3. (lands, distant)
4. (at, theatre)
5. (explore, 1, 3)
6. (saw, 1, movie)
7. (6, recently)
8. (inspired, 1, movie)

42. The outrageous stories that the drunken host told at the barbecue amused some guests and offended others.

1. (stories, outrageous)
2. (host, drunken)
3. (guests, some)
4. (at, barbecue)
5. (told, host, stories)
6. (amused, stories, guests)
7. (offended, stories, others)
8. (and, 6, 7)

43. The waitresses at this busy restaurant hate picky customers who take a long time to order their food.

1. (restaurant, busy)
2. (restaurant, this)
3. (customers, picky)
4. (time, long)
5. (food, their)
6. (at, restaurant)
7. (hate, waitresses, customers)
9. (take, customers, time)
10. (order, customers, food)

44. The pregnant woman shyly thanked the passenger who politely offered her his seat on the crowded bus.

1. (woman, pregnant)
2. (seat, his)
3. (bus, crowded)
4. (on, bus)
5. (thanked, 1, passenger)
6. (5, shyly)
7. (offered, passenger, her, 2)
8. (7, politely)

45. The gardener gently watered some yellow tulips that he had planted along the sides of a winding path.

1. (tulips, yellow)
2. (tulips, some)
3. (path, winding)
4. (of, path)
5. (along, sides)
6. (planted, gardener, tulips)
7. (watered, gardener, tulips)
8. (7, gently)

APPENDIX F

Stimuli for Listening Span Task

1. The house quickly got dressed and went to work.
2. I took a knapsack from my shovel and began removing the earth.
3. The lamp bucked and sent the horse tumbling to the ground.
4. The cop spent a good half-hour questioning his trusted friend.
5. People are given by money at Christmas time.
6. She worked quickly but quietly while the others were asleep.
7. It was a foggy day and everything was dripping wet.
8. The girl was awakened by the gusts of rain blowing against the house.
9. The story started as a joke, but soon got out of hand.
10. He quickly put the carrot in the ignition and started the car.
11. The murky swamp slipped into the waters of the crocodile.
12. The castle sat nestled in the refrigerator above the tiny village.
13. It wasn't all her fault that her marriage was in trouble.
14. When he reached the top of the heart, his mountain was pounding.
15. The barn raged through the abandoned old fire.
16. With a frown of pain, the old ranger hung up his hat forever.
17. The man fidgeted nervously, once again checking his watch.
18. Clouds of cigar smoke wafted into the open eraser.
19. Convictions for all offenses increased from the turn of the century.
20. He was pleased to receive so much love and attention.
21. The warrior was completely clothed from head to toe with deadly spikes.
22. The oven stretched over the rapidly moving bridge.
23. I couldn't believe he fell for the oldest book in the trick.
24. The scrapyard outside the old cabin was filled with discarded metal junk.
25. Torrential rains swept over the tiny deserted island.
26. They waited at the water's edge, the raft bobbing up and down.
27. I let the potato ring and ring, but still no answer.
28. The red wine looked like blood on the white carpet.
29. The children put on their closets and played in the snow.
30. He stood up and yawned, stretching his arms above his head.
31. The young girl wandered slowly down the winding path.
32. The purpose of the course was to learn a new language.
33. The sock set the table, while I made dinner.
34. At some life, everyone ponders the meaning of point.
35. The bars roared and began banging on the ape of the cage.
36. Being sued for malpractice was the doctor's main concern.
37. The shampoo was vibrant with music, theatre, and dance.
38. The class homework was done by everyone in the history.
39. Thick foliage surrounded him, and the air was heavy and still.
40. The deserted calendars rocked mournfully, driven by the wind and the tide.

41. The men were all gathered for a training flight near the base.
42. The sudden grizzly bear caused the noise to look in our direction.
43. The coral reefs support an infinite variety of beautiful marine life.
44. The crowd parted, waiting for someone to pass through.
45. As the flower talked about its busy life, it began to cry.
46. An eerie breeze suddenly chilled the warm, humid air.
47. As the ideas flowed, I jotted them down on some water.
48. The flash was dark, lit only by the occasional room of lightning.
49. He stepped back as the ghoul moved forward.
50. The robber bounded across the bridge and entered the dimly lit garage.
51. Three of the pillows were dead and he was next.
52. My escape out of the telephone was blocked by a wire fence.
53. She turned around and sucked in a startled breath.
54. They ran until their lungs felt like they were going to burst.
55. The additional evidence helped the verdict to reach their jury.
56. No one ever figured out what caused the crash to plane.
57. His eyes were bloodshot and his face was pale.
58. As a full-time university student, he studied hard.
59. The CN Tower raced across the sailboat to the finish line.
60. Somewhere in the deepening twilight, a loon sang its haunting evening song.
61. The fish glided majestically into the deepening recipe and was gone.
62. Gender roles persist because their roots are deep.
63. His men now flatly refused to continue with the journey.
64. The forest passed and the dead echo regained its quiet.
65. The letter burned until all that remained was a bit of ash.
66. The thought of going back in there made my skin crawl.
67. The wind started as a distant whisper, but soon began to howl.
68. They ran like the wind but they would never get away.
69. She couldn't wait to go to the zoo to visit her cheese.
70. I waited a few hours, holding my breath, watching the loud silence.
71. Trails are supposed to stay on the hikers, but they usually don't.
72. He stormed out without giving me so much as a backward glance.
73. The paperclip was flaked white and red with sunburn.
74. Returning with an eagle, a branch breaks to land at its nest.
75. A television droned from the dark interior of the apartment.
76. They talked about what the world would be like after the war.
77. His mouth was twisted into an inhuman smile.
78. Silverware clunked, drawers slammed, and closet doors were wrenched open.
79. A welt was forming on his bottle where the forehead made contact.
80. I'd been naïve to think he would fall into my trap.
81. The piercing yellow eyes glowed hauntingly in the mist.
82. The beach hung down over the window, filtering the moonlight from outside.
83. These operations are only done as a last resort.
84. The first impression is often a lasting one.
85. The throat tightening around her arm turned her scream into a croak.
86. The soap hovered over the elephant, waiting to attack.

87. They watched in silence as a brilliant carpet dipped behind the horizon.
88. The rumbling of the distance faded into the feather.
89. The sun had gone and the evening skies were tinted purple.
90. Opposite the chimney doorway was the yawning cabin mouth.
91. Usually the visual images are the ones people remember best.
92. She crept towards the door, following the moving shadow.
93. A deafening cheer rose up from the kids watching the parade.
94. A blue-uniformed security guard moved quickly out of the dog.
95. She wore a huge, white dress bigger than a camping tent.
96. He popped the sandwich into the VCR and watched the movie.
97. A hush seemed to have fallen over the entire park.
98. The umbrella grabbed its bat and stepped up to the plate.
99. The starving hamburger bit into the juicy man.
100. The hurricane left a path of destruction through the tiny town.

APPENDIX G

Instructions for the Gap Detection Test

The purpose of this test is to find the smallest silent interval, or gap, that you can hear in a sound. To begin the test, you need to push the middle button on this response box. You will then hear two beep sounds. The green light on this box will light up when you hear the first sound and the red light will light up when you hear the second sound. One of these sounds will have a gap in it and one will not. Once you have heard both beeps, you need to indicate which of the sounds had the gap in it. If you think that the first sound had a gap in it, then push the button under the green light. If you think that the gap was in the second sound, then push the button under the red light. After you respond a light will flash above the correct answer. To hear the next two sounds, press the middle button on this response box. You need to press this button each time to begin a new trial. The gap you are listening for will get smaller and harder to hear. This is normal. Just do your best and indicate which beep had the gap in it.

APPENDIX H

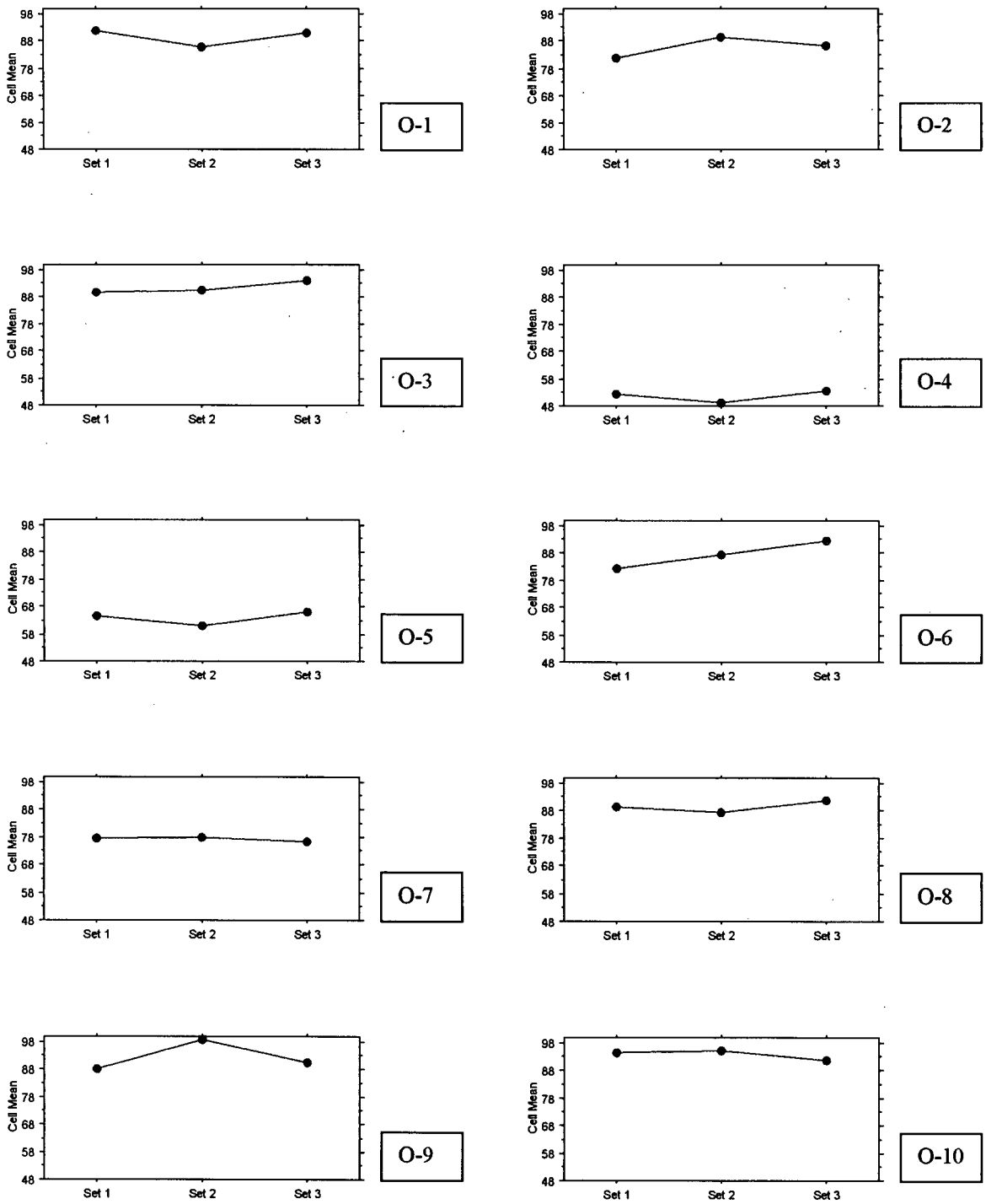
Individual Participant Data for Experimental Measures

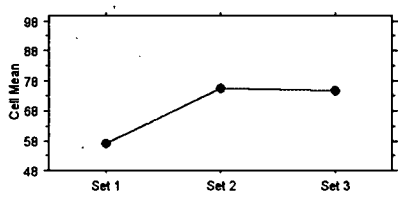
Participant	Listening Span	Digit Span	Gap Detection Threshold (ms)	Mean Reaction Time (s)
O-1	3.5	6	4.81	1.57
O-2	2.0	4	.	2.07
O-3	2.0	7	6.31	1.20
O-4	0.0	3	8.67	1.60
O-5	2.0	6	7.25	2.26
O-6	2.5	6	4.14	.86
O-7	2.0	4	6.30	1.09
O-8	.5	4	4.39	.43
O-9	2.0	4	5.16	1.27
O-10	2.0	6	4.55	.79
Y-1	.5	6	3.89	3.17
Y-2	4.0	7	3.13	.42
Y-3	4.0	6	4.40	.62
Y-4	2.0	5	2.20	1.14
Y-5	4.0	7	5.45	.63
Y-6	4.0	5	4.41	.48
Y-7	3.5	6	3.09	1.41
Y-8	3.5	5	4.17	.78
Y-9	3.5	4	5.42	.84
Y-10	3.5	7	2.72	.76

Note. Participant O-2 was unable to perform the gap detection test. O = Old and Y = Young.

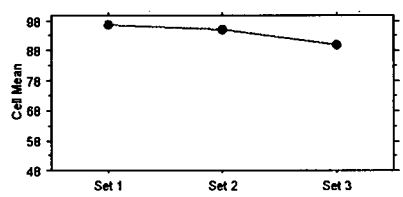
APPENDIX I

Mean Word Recall by Set Position for Each Participant in the First Compressed Rate Block

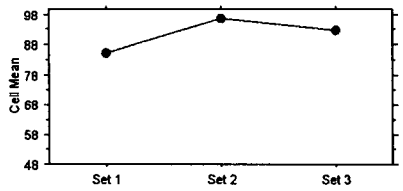




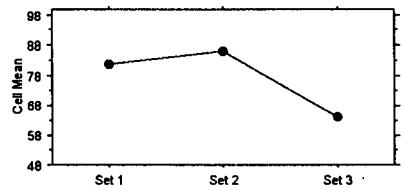
Y-1



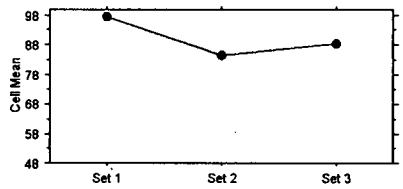
Y-2



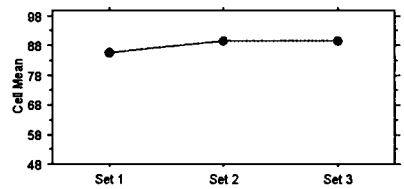
Y-3



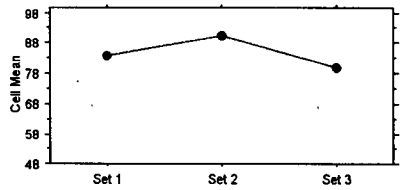
Y-4



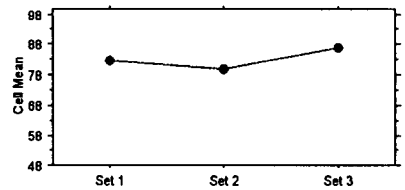
Y-5



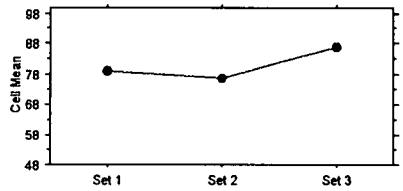
Y-6



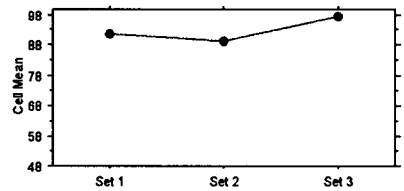
Y-7



Y-8



Y-9



Y-10

Note. O = Old and Y = Young.