The Effects of Aging on Human Memory and Learning

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Abstract

Much research has gone into understanding cognitive declines in aging. Using healthy young and older adults, we examined age-related changes in general and specific abilities associated with human memory and learning.

In Experiment 1, we examined age-related changes in episodic memory using free and serial recall for lists of unrelated words. Older adults made fewer correct responses and more incorrect responses, although these differences were fairly modest. The largest age-associated declines appeared when order information was taken into account, suggesting that older adults have more difficulty establishing or maintaining temporal context in list memory. These difficulties selectively affected recall for early and middle list items. Moderate changes in presentation rate affected both age groups equally.

Experiment 2 addressed perceptual learning for time-compressed speech. We replicated previous findings (Peelle & Wingfield, under review) showing with repeated exposure to time-compressed speech, young and older adults achieve similar levels of improvement when equated for starting accuracy. We demonstrated that these same levels of short-term improvement can be achieved when intervening uncompressed sentences or pauses are presented during the learning period. However, age differences were revealed for long-term carryover of learning. Whereas young adults showed consistent increases in baseline ability and rate of re-learning from week to week, older adults demonstrated no such pattern.

We conclude that a large range of age-associated deficits and preservations exist in the domains of learning and memory. When combined, these deficits and preservations result in an overall effect of moderate decline in cognitive ability with age.
Introduction

In the cognitive domains of learning and memory, popular wisdom suggests that older adults are at a disadvantage compared to their younger counterparts. It is true that even normal, healthy aging is accompanied by declines in mental performance. But while some mental abilities are considerably impaired in older adults, others remain relatively well preserved. Because of the importance of learning and memory in daily life, declines in these abilities have been a prevailing impetus for study over the years.

Much debate has centered on the causes of these cognitive declines (reviewed in Parkin & Java, 2000). One popular hypothesis is based on reduced processing resources in older adults (see Light, 1991, for review), particularly decreased processing speed (Salthouse, 1996). Another hypothesis suggests that older adults are more susceptible to different types of interference, making cognitive tasks more difficult (see Salthouse, 1991, for review). Others draw on physiological evidence of age-related neuronal loss, particularly in the prefrontal cortex, which is responsible for executive functioning (Backman, Small, & Wahlin, 2001). The present study does not attempt to provide direct evidence supporting any of these theories; rather, it aims to provide an in-depth analysis of specific components of learning and memory that deteriorate or are preserved with age.

Memory is often divided into two realms: episodic and semantic (Tulving, 1983). Episodic memory is memory for events, including such time-sensitive tasks as word-list memorization. Semantic memory involves general knowledge not tied to a specific context. While semantic memory remains relatively preserved with age, many older adults encounter difficulties in episodic memory (Backman, Small, & Wahlin, 2001; Salthouse, 1991).
Experiment 1 addresses episodic memory using immediate recall for lists of unrelated words. Two types of recall, free and serial, are compared. The inter-item presentation rate is also varied to examine potential age differences in free and serial recall under conditions of increased processing load.

In addition to difficulties with episodic memory, another common source of complaint among the aging population is comprehension of rapid speech. Although older adults generally have little difficulty understanding normal speech (Burke, Mackay, & James, 2000), their comprehension of rapid speech is significantly impaired (Wingfield, Poon, Lombardi, & Lowe, 1985; Wingfield, Tun, Koh, & Rosen, 1999). Experiment 2 addresses perceptual learning for time-compressed speech. It examines participants' adaptation over time to a very rapid speech rate and assesses the effects of alternating slow and fast speech rates during the learning period for both age groups. Components of short-term and long-term learning are also addressed.

Experiment 1

In episodic memory, the recall process is often divided into three components: encoding, storage, and retrieval. In order for an item to be successfully recalled, a memory trace must first be created upon presentation, then held in memory for a certain period of time, and finally accessed at the desired point in time. If any of these components fail, correct recall is not possible. Because older adults' performance on recall tasks is often worse than young adults', much research has been devoted to understanding how these separate components are affected by age. A number of different hypotheses exist, attributing age-related deficits to processing or organization problems during encoding, interference during storage, and accessibility failure
during retrieval (discussed in Smith, 1980; Salthouse, 1991). Indeed, recent evidence seems to exist for difficulties at each of these stages. While some studies have demonstrated that older adults show less organization during recall (Kahana & Wingfield, 2000), implicating encoding deficits (see Naveh-Benjamin, 2000, “association deficit” hypothesis), other studies have indicated that encoding is not the main problem. For example, evidence exists that age-related encoding differences in chunking (Allen & Coyne, 1989) and subjective organization (Tulving, 1968) are not sufficient explanations for recall problems. As an alternative explanation, Foos (1989) found evidence for a smaller storage capacity and fewer total resources in older adults, implying that when the limited resources must be devoted to processing, less is available for temporary storage. On the other hand, Laurence (1967) showed that older adults’ recall improved when cues were given at the time of retrieval, suggesting that the encoding and storage processes remained intact. It thus seems likely that all three stages are affected to a certain degree by age.

In order to fully understand age-related changes in episodic memory, one must first characterize “normal” memory in young adults. A number of episodic memory tasks have been analyzed in great detail over the past century. These tasks examine recall (including free recall, serial recall, and associative pairing), recognition memory, and implicit memory. Compared to recognition and implicit memory, older adults have much more difficulty with recall, particularly recall of lists of semantically unrelated items (e.g., Burke & Light, 1981; Craik, 1977; Kausler, 1994), as found in free and serial recall. Free and serial recall tasks differ in that free recall requires memory only for items, whereas serial recall necessitates both item and order memory.

Free recall in particular has been used often to analyze episodic memory. Early analyses of free recall focused on the importance of the serial position curve (Murdock, 1962; Deese,
1957). Essentially, when presented with a list of items that is too large for the working memory span, a person cannot remember every item. The items selectively remembered, however, are not arbitrary, but follow a very specific pattern. By plotting the probability of correct recall as a function of serial position in the list, one obtains the serial position curve. The serial position curve exhibits two striking qualities: a strong recency effect, whereby words presented at the end of the list are extremely well-recalled, and a weaker primacy effect, whereby words presented at the very beginning of the list are also likely to be recalled. Words falling in the middle of the list, however, are often omitted during recall, resulting in a J-shaped curve.

Postman and Phillips (1964) found that when participants were subjected to a distractor task between presentation and recall, however, the large recency effect was greatly reduced, whereas the primacy and middle portions of the curve remained unchanged. This led many researchers to characterize free recall and the serial position curve in terms of recency and pre-recency. Additional analyses examining the effects of factors such as presentation rate (Glanzer & Cunitz, 1966; Murdock, 1962), word-frequency (Smyth, 1963; Raymond, 1969), semantic similarity (Craik & Levy, 1970; Glanzer, 1976), phonological/acoustic similarity (Craik, 1968; Shallice, 1975), and list length (Murdock, 1962) further enforced this distinction. Evidence began to accumulate in support of a two-store model of memory (e.g., Waugh & Norman, 1965; Atkinson & Shiffrin, 1968), in which recency effects were due to short-term or primary memory, and pre-recency effects were due to long-term or secondary memory. According to this model, factors such as presentation rate, word-frequency, semantic similarity, and list length affect only the pre-recency portions of the serial position curve, whereas phonological/acoustic similarities and post-list delays or distractions affect only the recency component.
Furthermore, when age was assessed as a variable, it was initially found to selectively affect pre-recency (Craik, 1968, 1977). Basing his conclusions on statistical analyses of primary and secondary memory, Craik found that age differences in immediate recall were limited to secondary memory. However, this selective impairment has not been consistently corroborated by subsequent studies. In fact, most studies of aging and recall have found that older age results in commensurate decreases across all areas of the serial position curve; the curve maintains the same shape with age, just at a lower magnitude (e.g., Kahana, Howard, Zaromb, & Wingfield, 2002; Parkinson, Lindholm, & Inman, 1982; Capitani, Della Sala, Logie, & Spinnler, 1992; Spinnler, Della Sala, Bandera, Baddeley, 1988).

While the two-store theory was initially widely accepted, it has more recently been subjected to much criticism (e.g., Greene, 1986). One of its most conspicuous faults is that it fails to explain recall in the continuous-distractor task, in which a distractor is presented between each item of the list. The two-store model would predict a decrease in the recency effect similar to that seen when a distractor is presented following the list, since the distractors should force the previous items out of short-term memory. This is not the case, however; the continuous distractor task results in a serial position curve more closely related to immediate recall than delayed recall (Bjork & Whitten, 1974). It seems that the strength of the recency effect is due to the ratio of the post-list delay to the inter-item delays, summarized with the ratio rule (Bjork & Whitten, 1974; Glenberg, Bradley, Kraus, & Renzaglia, 1983; Naime, Neath, Serra, & Byun, 1997).

While the theoretical basis for the recency effect has stirred up considerable controversy, the explanations underlying the primacy effect are fairly well accepted. Primacy is thought to be due to increased rehearsal of the initial items (Brodie & Murdock, 1977; Rundus, 1971; Tan &
Ward, 2000). The first few items can be rehearsed relatively easily, but with increased items comes increased load and interference. Studies using the overt rehearsal technique, in which participants are asked to say out loud whatever they are thinking, support this theory of increased rehearsal for initial items (e.g., Rundus, 1971). The overt rehearsal technique has also been used to create a functional serial position curve, in which serial position is assigned based on the order of rehearsal. As opposed to the more traditional nominal serial position curve (based on order of presentation), the functional serial position curve shows no primacy effects, only recency (Tan & Ward, 2000; Murdock & Metcalfe, 1978). Factors traditionally affecting only pre-recency in nominal curves affect only recency in functional curves (Tan & Ward, 2000). The primacy effect can likewise be removed from nominal serial position curves when rehearsal is eliminated or minimized by instructing participants to concentrate only on the current word being presented (Welsh & Burnett, 1924).

While the serial position curve is very useful in characterizing recall based on input, it does not allow for the characterization of recall based on output. Analyzing output patterns can provide important insight into the memory process. A number of early studies looked at response bursting, in which participants tend to recall words clustered by semantic category (Bousfield, 1953). The interresponse times (IRTs) between items recalled within a category are much shorter than IRTs between categories (Pollio, Richards, & Lucas, 1969). Wingfield, Lindfield, and Kahana (1998) demonstrated that both young and older adults show this classic response bursting pattern. By analyzing the IRTs, they concluded that the older adults' retrieval difficulties were due mainly to difficulties accessing the semantic categories, not accessing items within a category (Wingfield, Lindfield, & Kahana, 1998). This has been supported by studies in which older adults' performance was aided by cued retrieval (e.g., Laurence, 1967).
In a related form of organization, output patterns often represent the subjective organization that occurs during encoding (Tulving, 1962). This refers to the tendency to consistently group items together during repeated trials of free recall, even when the order of presentation of these items is varied from trial to trial. Tulving (1962) demonstrated that participants who engage in this subjective organization tend to perform better on recall tasks. Indeed, a number of studies have focused on participants’ tendencies to impose order on free recall of unrelated words, through formation of both categories (response bursting) and sequences (subjective organization) (e.g., Bousfield & Bousfield, 1966). Since aging studies have shown that item memory is maintained but associations between items are weakened with age (Naveh-Benjamin, 2000), one might expect that these organizational tendencies are less prevalent or effective in older adults.

More recently, a number of studies have focused on the temporal organization and output patterns during recall (e.g., Howard & Kahana, 1999, 2002a). Howard and Kahana described output order in terms of two phenomena: how participants initiate recall and how they make transitions between items being recalled. As first noted by Deese and Kaufman (1957), participants tend to begin recall with items occurring near the end of the list. This can be measured by plotting a serial position curve for only the first item recalled, representing the probability of first recall (PFR). For immediate free recall, a PFR curve shows that participants almost always begin recall with items from the final few positions in a list, with a very small recall probability for beginning recall with the first word and almost never for words falling in the middle of a list (Howard & Kahana, 1999, 2002a).

The relationship between subsequent recalls can also be quantified. Kahana (1996) first looked at the relationship between recall probability and the separation in items during
presentation (lag) between two consecutive recalls. (If items \(a, b, c,\) and \(d\) are presented in that order, \(d\) is at a lag of +1 from \(c,\) and \(a\) is at a lag of -2 from \(c.\)) This conditional response probability as a function of lag (lag-CRP) illustrates that items occurring together during presentation are more likely to be recalled together than are items presented farther apart, a phenomenon termed the **lag-recency effect**. Furthermore, this effect is asymmetric, favoring forward associations over backward associations (Howard & Kahana, 1999; Kahana, 1996).

Taken together, the PFR and lag-CRP can provide much information about the dynamics of retrieval that produce the traditional serial position curve. While the PFR can be a good indicator of the recency effect in immediate free recall, the lag-CRP corresponds to pre-recency activity. Several recent studies have examined the role these temporal retrieval processes play in aging (e.g., Wingfield & Kahana, 2002; Howard, Wingfield, & Kahana, under review; Kahana, Howard, Zaromb, & Wingfield, 2002). While the serial position curves for the older adults were approximately parallel to those of the young adults, with slightly less age difference during recency, the PFR was entirely unaffected by age, and the lag-CRP showed a considerably decreased lag recency effect for the older group (Wingfield & Kahana, 2002; Howard, Wingfield, & Kahana, under review; Kahana, Howard, Zaromb, & Wingfield, 2002). This illustrates that while older adults initiate recall in the same way as the young adults, their temporal organization of the study items is not as strong.

Although temporal organization of items may aid a participant during free recall, temporal organization is clearly more important for serial recall. Since older adults appear to show weaker temporal organization during free recall, one might expect them to find the serial recall task particularly difficult. Interestingly, while a large number of studies have examined
free recall and aging, few have looked at serial recall and aging. Furthermore, none of these have conducted a comparison of free and serial recall in older adults within a single experiment.

Whereas free recall requires memory for item information, serial recall involves the additional requirement of order information. Of the two types of recall, studies of serial recall are considerably less abundant in memory literature. Most studies of serial recall focus on one of two purposes, either to differentiate between item and order contributions via comparisons to free recall, or to better understand real-life situations which require both order and item information, such as memory for language or telephone numbers.

The serial position curve takes a quite different shape for serial recall than for free recall (Deese, 1957; Jahnke, 1965). In serial recall the primacy effect is very strong, with a weaker recency effect. There is evidence that successful serial recall involves a different encoding process (Detterman & Brown, 1974). Detterman and Brown had participants perform either free or serial recall on a given trial, with instructions given either before or after list presentation. They found that successful serial recall depended on more than a different retrieval strategy; optimal performance was found only when instructions were given beforehand.

A widely accepted belief is that serial recall makes use of the *phonological loop* component of working memory (Baddeley, 1986). The phonological loop is used for the temporary storage of verbal information and is composed of two systems: a passive phonological store and an active articulatory rehearsal. A memory trace will quickly fade from the passive store unless it is actively rehearsed. The large primacy effect can thus be attributed to the number of items that can “fit” in the rehearsal loop. The smaller recency effect would be due to items that have not been rehearsed but have not yet faded from the passive store.
As with free recall, older adults show deficits with serial recall (e.g., Maylor, Voulsen, & Brown, 1999; Maylor & Henson, 2000; Allen & Crozier, 1992). While a few models exist that can account for both free and serial recall (mainly ACT-R: Anderson, Bothell, Lebiere, & Matessa, 1998; and convolution-correlation: Metcalfe & Murdock, 1981; Lewandowsky & Murdock, 1989), they have not been tested on older adults. Because comparing free and serial recall can provide more information than examining them separately, it is surprising that this endeavor has not yet been undertaken. In this study, we aim to systematically examine free and serial recall in young and older adults using single-trial, immediate recall of unrelated words. We also examine the effect of presentation rate on free and serial recall and on age.

**Method**

*Participants.* There were 24 participants in the young group and 24 in the older group. The young group (10 men and 14 women) was composed of Brandeis University undergraduates aged 18-22 ($M = 19.8$, $SD = 1.5$). They had a mean of 14.2 years of education at the time of testing ($SD = 1.3$) and a mean Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1997) vocabulary score of 48.7 ($SD = 6.1$). They had a mean forward digit span of 7.8 items ($SD = 1.0$) and a mean backward digit span of 5.8 ($SD = 1.1$).

The older group (9 men and 15 women) was composed of community-dwelling adults aged 65-85 ($M = 73.4$, $SD = 4.7$). They had a mean of 16.5 years of education ($SD = 1.9$) and a mean WAIS vocabulary score of 50.8 ($SD = 6.3$). Their mean forward digit span was 7.7 items ($SD = 1.0$), and their mean backward span was 6.1 ($SD = 1.4$).

Both groups were thus well-educated, with the older group having an average of 2.3 more years of formal education, $t(46) = 4.79$, $p < .001$. The two groups were statistically equivalent in
tests of vocabulary, \( t(46) = 1.19, \text{n.s.} \), forward digit span, \( t(46) = 0.59, \text{n.s.} \), and backward digit span \( t(46) = 0.81, \text{n.s.} \). All participants were native English speakers and reported themselves to be in good health. They were compensated with a small monetary sum for their participation.

*Stimuli.* Stimuli were 846 two-syllable nouns with similar ratings for concreteness, familiarity, imagery, and Kucera-Francis frequency. Each participant received a total of 80 lists of ten words each, selected at random and without replacement from the word-pool.

*Procedure.* Participants participated in two separate sessions of approximately 40 minutes each. For half of the participants, their first session was a free recall task and their second session was a serial recall task. The other participants performed the tasks in the reverse order. The sessions occurred at least one week apart to minimize possible carryover in strategy from the previous session's task.

At the start of the task, participants were given instructions for either free or serial recall, followed by four practice trials. The practice trials were immediately followed by 36 test trials. Participants were cued to press the spacebar to begin each trial. A tone signaled the beginning of presentation. Words were presented one at a time in capital letters in the center of the computer screen for 1000 ms, followed by a blank ISI. ISIs were either 800 ms, 1200 ms, or 2400 ms long. Within a given list, all ISIs were the same, and trials were blocked according to ISI. Each session consisted of one block of 12 trials for each of the three presentation rates. The order of these blocks was counterbalanced across participants, and each participant received the same order for both of their sessions. Participants were informed at the beginning of each block whether they would be receiving the “fast”, “medium”, or “slow” presentation rate.

As each word appeared on the screen, participants were instructed to say the word out loud. After the final word was presented, three asterisks appeared on the screen accompanied by
a tone. This was the signal to begin recall. During recall, participants were instructed to speak loudly and clearly and avoid repetitions and extraneous noises. Participants’ responses were recorded on the computer using a microphone. Participants were given up to one minute to recall as many words from the list as possible, although they could press the spacebar at any point to indicate they were finished recalling. Participants were then either given the option to take a break or to continue on to the next trial.

Analyses. The word recalled, output position, and time of word onset were noted for each response. If the word had appeared in the list, its input position was noted as well. Plural versions were considered matches. Words were judged correct according to one of two scoring methods. In item scoring, words were correct if they appeared in the most recent list, regardless of position. In relative order scoring, a word was considered correct only if it appeared later in the list than the previously recalled item. First responses were always correct, and intrusions were ignored. Unless otherwise noted, all results are based on item scoring. Also, unless otherwise noted, repetitions were ignored, and analyses were based on the first instance of occurrence.

Results

Figure 1 shows the average number of words correct per list for each of the experimental conditions. Averages are given for the young and older adults performing free and serial recall tasks at the three different presentation rates. The left panel gives the averages obtained using item scoring. At each rate and task, the young group correctly recalled a higher number of words per list than the older group, although these age differences were fairly modest. The right panel gives the averages for the same conditions based on relative order scoring. The stricter scoring
method resulted in fewer words correctly recalled in all conditions, although these differences were differentially larger for the older group. Regardless of scoring method, faster presentation rates resulted in poorer performance.

![Graph showing recall accuracy for different conditions](image)

*Figure 1. Average recall accuracy for each condition based on item and relative order scoring methods.*

The data were submitted to a 2 (Scoring Method: Item, Relative Order) X 2 (Task: Free Recall, Serial Recall) X 3 (Rate: Slow, Medium, Fast) X 2 (Age: Young, Older) mixed design analysis of variance (ANOVA), with Scoring Method, Task, and Rate as within-participants variables. The main effect of Age was significant, $F(1,45) = 4.46, MSE = 5.846, p < .05$, supporting the observation that older adults are less successful at recall tasks. Compared to item scoring, relative order scoring resulted in lower overall averages, as evidenced by a main effect of Scoring Method, $F(1,45) = 389.16, MSE = 0.490, p < .001$, with differentially lower averages for older adults, indicated by a significant Scoring Method X Age interaction, $F(1,45) = 5.45, MSE = 0.490, p < .05$.

There was no significant main effect of Task, $F(1,45) = 1.58 (MSE = 0.955)$, or Task X Age interaction, $F(1,45) = 2.09 (MSE = 0.955)$. There was, however, a significant Task X
Scoring Method interaction, $F(1,45) = 119.23$, $MSE = 0.329$, $p < .001$, indicating that free recall scores were significantly better than serial recall scores when only item information was taken into account, whereas the opposite was true when both order and item information were considered. The Task X Scoring Method X Age interaction, $F(1,45) = 1.26 (MSE = 0.329)$, was not significant, however, since both age groups displayed this same pattern of performance.

The significant main effect of Rate, $F(2,90) = 19.21$, $MSE = 0.328$, $p < .001$, confirmed the observation that lists presented at faster rates are more difficult to recall. The Rate X Age interaction was not significant, $F(2,90) = 1.96 (MSE = 0.328)$, indicating that presentation rate affects both age groups equally. Presentation rate also affected both scoring methods equally, as evidenced by a lack of Rate X Scoring Method, $F(2,90) < 1 (MSE = 0.054)$, or Rate X Scoring Method X Age, $F(2,90) < 1 (MSE = 0.054)$, interaction. Similarly, presentation rate had an equal effect on free and serial recall tasks, as there were no Rate X Task, $F(2,90) = 1.55 (MSE = 0.216)$, or Rate X Task X Age, $F(2,90) = 1.53 (MSE = 0.216)$, interactions. Rate X Scoring Method X Task, $F(2,90) = 1.03 (MSE = 0.046)$, and Rate X Scoring Method X Task X Age, $F(2,90) < 1 (MSE = 0.046)$, interactions were also absent.

Figure 2 displays the serial position curves for young and older adults performing free and serial recall tasks at each of the three presentation rates. The free recall curves all show the traditional J-shaped curve with large recency and smaller primacy effects, while the serial recall curves are more U-shaped, with an increase in primacy and a decrease in recency. Older adults seem to be performing worse than the younger adults, although this difference is limited to the pre-recency sections and is rather small, particularly in free recall, where the serial position curves lie almost on top of one another.
Figure 2. Serial position curves for young and older adults at the three presentation rates. Serial position curves were calculated using item scoring for free recall and both item (I) and relative order (RO) scoring for serial recall. Error bars represent 1 SE.

In comparing the serial position effects for each of the conditions, we were primarily concerned with the relative levels of primacy and recency. Following Klein, Addis, and Kahana (under review), we divided the serial position curve into three bins. The primacy region included serial positions 1-3, the middle region included positions 4-6, and the recency region included positions 7-10. The free and serial recall tasks were first compared using averages for these bins calculated by the item scoring method (upper and middle panels of Figure 2). The data were submitted to a 2 (Task: Free Recall - item, Serial Recall - item) X 3 (Rate: Slow, Medium, Fast)
X 3 (Serial Position Bin: Primacy, Middle, Recency) X 2 (Age: Young, Older) mixed design
ANOVA, with Task, Rate, and Serial Position Bin as within-participants variables. As expected,
the main effect of Serial Position Bin was significant, \( F(2,92) = 81.90, \text{MSE} = 0.083, p < .001 \),
indicating that the primacy, middle, and recency regions of the serial position curve did not
produce equal levels of accuracy.

The main effects of Task, \( F(1,46) = 7.42, \text{MSE} = 0.020, p < .01 \), and Rate, \( F(2,92) =
18.83, \text{MSE} = 0.007, p < .001 \), were also significant, reiterating that performance is significantly
worse on serial recall than on free recall, and that recall suffers with increasingly rapid
presentation rates. These two factors also affect the shape of the serial position curve, as
evidenced by significant Task X Serial Position Bin, \( F(2,92) = 76.81, \text{MSE} = 0.018, p < .001 \),
and Rate X Serial Position Bin, \( F(4,184) = 18.39, \text{MSE} = 0.008, p < .001 \), interactions.
However, there were no significant Task X Rate, \( F(2,92) < 1 (\text{MSE} = 0.004) \), or Task X Rate X
Serial Position Bin, \( F(4,184) < 1 (\text{MSE} = 0.008) \), interactions, indicating that presentation rate
changes do not affect one task more than the other.

Somewhat surprisingly, there was no significant main effect of Age, \( F(1,46) = 2.13 (\text{MSE}
= 0.120) \). Likewise, none of the age-related interactions was significant, including Task X Age,
\( F(1,46) < 1 (\text{MSE} = 0.020) \), Rate X Age, \( F(2,92) = 1.57 (\text{MSE} = 0.007) \), Serial Position Bin X
Age, \( F(2,92) = 1.08 (\text{MSE} = 0.083) \), Task X Rate X Age, \( F(2,92) = 1.47 (\text{MSE} = 0.004) \), Task X
Serial Position Bin X Age, \( F(2,92) < 1 (\text{MSE} = 0.018) \), Rate X Serial Position Bin X Age,
\( F(4,184) < 1 (\text{MSE} = 0.008) \), and Task X Rate X Serial Position Bin X Age, \( F(4,184) = 1.68
(\text{MSE} = 0.008) \).

Comparing free and serial recall using item scoring fails to give a complete account of
differences between the two tasks, however, since serial recall requires order memory as well. A
separate analysis was thus performed comparing free recall averages calculated from item scoring and serial recall averages calculated from relative order scoring (top and bottom panels of Figure 2). The data were submitted to a 2 (Task: Free Recall - item, Serial Recall - relative order) X 3 (Rate: Slow, Medium, Fast) X 3 (Serial Position Bin: Primacy, Middle, Recency) X 2 (Age: Young, Older) mixed design ANOVA, with Task, Rate, and Serial Position Bin as within-participants variables.

As in the previous analysis, the main effects of Serial Position Bin, $F(2,92) = 96.26$, $MSE = 0.072, p < .001$, Task, $F(1,46) = 79.62$, $MSE = 0.019, p < .001$, and Rate, $F(2,92) = 23.61$, $MSE = 0.006, p < .001$, were significant, as were Task X Serial Position Bin, $F(2,92) = 77.96$, $MSE = 0.017, p < .001$, and Rate X Serial Position Bin, $F(4,184) = 18.89$, $MSE = 0.008, p < .001$, interactions. Also consistent with the previous analysis, Rate X Age, $F(2,92) = 1.47$ ($MSE = 0.006$), Serial Position X Age, $F(2,92) < 1$ ($MSE = 0.072$), Task X Rate, $F(2,92) = 1.55$ ($MSE = 0.004$), Task X Rate X Age, $F(2,92) = 2.01$ ($MSE = 0.004$), Task X Serial Position Bin X Age, $F(2,92) < 1$ ($MSE = 0.017$), Rate X Serial Position Bin X Age, $F(4,184) < 1$ ($MSE = 0.008$), Task X Rate X Serial Position Bin X Age, $F(4,184) < 1$ ($MSE = 0.007$), and Task X Rate X Serial Position Bin X Age, $F(4,184) = 1.76$ ($MSE = 0.007$), interactions were not significant.

Unlike the comparisons based solely on item information, however, analyses taking order information into account for serial recall revealed some age differences. A comparison of item scoring for free recall and relative order scoring for serial recall exhibited both a main effect of Age, $F(1,46) = 4.59$, $MSE = 0.122, p < .05$, and a Task X Age interaction, $F(1,46) = 5.60$, $MSE = 0.019, p < .05$, neither of which was significant in the item analysis. This shows that while older adults are able to recall a similar number of items, they are significantly less likely to recall these items in order, resulting in poorer serial recall.
To decompose the serial position curve into its temporal components, PFRs and lag-CRP were calculated and are shown in Figure 3. Because presentation rate had negligible effect on these measures, the PFR and lag-CRP analyses were collapsed across presentation rate for the two age groups and two tasks. The upper panels of Figure 3 give the PFR curves. For free recall, the probability of first recall is heavily weighted toward the recency region, while serial recall shows the opposite tendency. Regardless of task, older adults appear to recall the last word first more often than the young adults.

Figure 3. Probability of first response (PFR) and conditional response probability as a function of lag (lag-CRP) for both age groups performing free and serial recall. Averages are collapsed across presentation rate. Error bars represent 1 SE.
To analyze the PFR results, serial position was again binned into primacy, middle, and recency regions. The data were submitted to a 2 (Task: Free Recall, Serial Recall) X 3 (Serial Position Bin: Primacy, Middle, Recency) X 2 (Age: Young, Older) mixed design ANOVA, with Task and Serial Position Bin as within-participants variables. As expected, the main effects of Task, $F(1,45) = 41.62, MSE < 0.001, p < .001$, and Serial Position Bin, $F(2,90) = 30.20, MSE = 0.006, p < .001$, were significant, in addition to the Task X Serial Position Bin interaction, $F(2,90) = 105.67, MSE = 0.004, p < .001$, supporting the observation that participants tend to begin recall with late items during free recall and early items during serial recall. PFR was not affected by age differences, confirmed by the lack of main effect of Age, $F(1,45) < 1 (MSE < 0.001)$, and Task X Age, $F(1,45) < 1 (MSE < 0.001)$, Serial Position Bin X Age, $F(2,90) = 2.08 (MSE = 0.006)$, and Task X Serial Position Bin X Age, $F(2,90) < 1 (MSE = 0.004)$, interactions.

It is possible, however, that binning the PFR data into regions may have obscured subtle age differences at the first and last serial positions. To compare the PFR of young and older adults at each of these points, post-hoc t-tests were performed. For the free recall tasks, there were no significant age differences at serial position 1, $t(46) = 1.07, n.s.$, nor at serial position 10, $t(46) = 1.62, n.s.$, confirming that both age groups follow the same pattern of initiating recall during free recall tasks. For serial recall, however, although there was no significant age difference at serial position 1, $t(46) = 0.07, n.s.$, there was a significant difference at serial position 10, $t(46) = 2.47, p < .05$. This indicates that while both age groups are equally likely to begin recall with the first item, if that item is not recalled first, the young adults appear to distribute their first recall equally among the other nine items, whereas the older adults are more likely to begin recall with the last item.
The lower panels of Figure 3 display the lag-CRPs of both age groups for free and serial recall. The forward asymmetry and lag recency effect (tendency to recall words appearing close together) are readily apparent in this figure. Both of these effects are more pronounced in the young group. Of note is the fact that while young and older adults tend to follow similar patterns of recall in the free recall task, a large age difference becomes apparent during serial recall. It is important to keep in mind that ideal performance during a serial recall task would consist of only lag +1 transitions, and thus the age difference here is critical.

In comparing the lag-CRPs, our main concern was with the conditional response probabilities at lags of +1 and -1. The data were thus submitted to a 2 (Task: Free Recall, Serial Recall) X 2 (Lag: +1, -1) X 2 (Age: Young, Older) mixed design ANOVA, with Task and Lag as within-participants variables. As suggested by the figure, conditional response probability was differentially affected by lag and task. Significant main effects of Task, $F(1,46) = 22.67, MSE = 0.006, p < .001$, and Lag, $F(1,46) = 291.10, MSE = 0.014, p < .001$, were seen in addition to a Task X Lag interaction, $F(1,46) = 12.07, MSE = 0.012, p < .001$. Although there was no main effect of Age, $F(1,46) = 2.72 (MSE = 0.015)$, or Task X Age interaction, $F(1,46) < 1 (MSE = 0.006)$, there was a marginal Task X Lag X Age interaction, $F(1,46) = 3.99, MSE = 0.012, p = .052$, as well as a significant Lag X Age interaction, $F(1,46) = 9.90, MSE = 0.014, p < .005$, illustrating differences in response patterns with age.

Although the above results have focused on the dynamics of correct responses, it remains to be seen whether age, rate, or task differences exist concerning incorrect responses. Figure 4 gives the frequencies of different types of incorrect recalls for each of the conditions. The upper panels reflect the two main types of incorrect response: repetitions, in which a participant repeats a word that has already been correctly recalled for the list, and intrusions, in which a participant
recalls a word that did not appear in the list. Intrusions can be divided into prior-list intrusions (words which appeared in a previous list) and extra-list intrusions (words which were never presented to the participant). The frequencies of these intrusion types are displayed in the lower two panels of the figure. The most striking feature in this figure is the resounding age difference; the older adults make more incorrect recalls of every type than do the young.

Figure 4. Average frequencies for different types of incorrect responses in each of the conditions.

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As a preliminary analysis, any intrusions that came from the word pool were assumed to be prior-list intrusions. The possibility exists that a word appearing in a later list was recalled as an intrusion. In this case, it would be incorrectly classified as a prior-list intrusion. Examination of the data indicates that this rarely, if ever, occurs. In addition, given the relatively large number of prior-list intrusions relative to extra-list intrusions, the overall trends should not be affected.
To compare the frequency of repetitions, a 2 (Task: Free Recall, Serial Recall) X 3 (Rate: Slow, Medium, Fast) X 2 (Age: Young, Older) mixed design ANOVA was conducted with Task and Rate as within-participants variables. Older adults made significantly more repetitions, as confirmed by the main effect of Age, $F(1,46) = 5.26$, $MSE = 0.090$, $p < .001$. Age was the only significant factor influencing repetition rate, however; there were no significant main effects of Task, $F(1,46) = 1.50$ ($MSE = 0.044$), or Rate, $F(2,92) < 1$ ($MSE = 0.010$), nor were there significant Task X Age, $F(1,46) < 1$ ($MSE = 0.044$), Rate X Age, $F(2,92) = 2.40$ ($MSE = 0.010$), Task X Rate, $F(2,92) < 1$ ($MSE = 0.012$), or Task X Rate X Age, $F(2,92) < 1$ ($MSE = 0.012$), interactions.

A similar analysis was conducted to assess differences in the number and type of intrusions per list for each condition. The data were submitted to a 2 (Intrusion Type: Prior-List, Extra-List) X 2 (Task: Free Recall, Serial Recall) X 3 (Rate: Slow, Medium, Fast) X 2 (Age: Young, Older) mixed design ANOVA, with Intrusion Type, Task, and Rate as within-participants variables. Although there appears to be a clear age difference in the frequency of total intrusions (upper right panel of Figure 4), there was only a marginal main effect of Age, $F(1,46) = 3.47$, $MSE = 0.546$, $p = .069$. The main effects of Task, $F(1,46) < 1$ ($MSE = 0.042$), and Rate, $F(2,92) = 1.03$ ($MSE = 0.031$), were not significant, nor were the Task X Age, $F(1,46) = 3.12$ ($MSE = 0.042$), Rate X Age, $F(2,92) < 1$ ($MSE = 0.031$), and Task X Rate, $F(2,92) = 1.20$ ($MSE = 0.027$), interactions. There was a marginal Task X Rate X Age interaction, $F(2,92) = 2.90$, $MSE = 0.027$, $p = .060$, suggesting that older adults may make more intrusions during free recall at certain rates where young adults make more serial recall intrusions.

While the number of total intrusions seems to be relatively consistent across all conditions, there were some interesting differences when intrusion type was taken into account.
Firstly, the number of prior-list intrusions per list was much higher than the number of extra-list intrusions, as proven by a significant main effect of Intrusion Type, $F(1,46) = 157.89, MSE = 0.204, p < .001$. This difference was exaggerated for the older group, as evidenced by a significant Intrusion Type X Age interaction, $F(1,46) = 4.88, MSE = 0.204, p < .05$. The frequencies of prior- or extra-list intrusions were not differentially affected by recall task or presentation rate, however, since there were no significant Intrusion Type X Task, $F(1,46) < 1 (MSE = 0.034)$, Intrusion Type X Rate, $F(2,92) < 1 (MSE = 0.035)$, Intrusion Type X Task X Rate, $F(2,92) < 1 (MSE = 0.027)$, Intrusion Type X Task X Age, $F(1,46) < 1 (MSE = 0.034)$, Intrusion Type X Rate X Age, $F(2,92) < 1 (MSE = 0.035)$, or Intrusion Type X Task X Rate X Age, $F(2,92) < 1 (MSE' = 0.027)$, interactions.

Discussion

The results from this experiment confirm that overall, older adults perform moderately worse than young adults on episodic memory tasks involving free and serial recall. While the older adults make fewer correct responses and more incorrect responses, their overall performance is not drastically worse than that of the young adults. In addition, certain specific abilities seem to be much more affected by age than others.

For both age groups, serial recall is more difficult than free recall, resulting in fewer correct responses. Since serial recall involves the additional requirement of memory for order in addition to item memory, this difference is expected and has been well established in the literature (e.g., Jahnke, 1965; Klein, Addis, & Kahana, under review). Serial recall is differentially difficult for older adults, however, especially when relative order scoring is used.
This is not surprising, as a number of studies have documented an age-related deficit in the ability to remember temporal information (see Kausler, 1994, for review).

While the overall figures demonstrate that older adults have difficulty with episodic recall, particularly serial recall, they fail to address the question of whether these age differences are generalized or attributable to certain specific deficits. Examining recall probability as a function of serial position provides some insight into these specific abilities, which can be further explored through decomposition into probability of first response and conditional response probabilities. Analyzing the frequency and type of incorrect responses also reveals interesting age differences.

The serial position curves in this experiment take the traditional shapes for free and serial recall—free recall has a very strong recency effect with a weaker primacy effect (Murdock, 1962), while serial recall has weaker recency and stronger primacy effects than free recall (Deese, 1957; Jahnke, 1965). For both tasks, however the primacy effect found in this experiment was weaker than expected (e.g., compare to Jahnke, 1965). This deviation can be attributed to a difference in procedure. In the present experiment, participants were required to read each word aloud as it appeared. This forced them to pay attention to each item in the list and presumably decreased rehearsal of earlier items in the list, thus decreasing the primacy effect.

While both age groups show these same J- and U-shaped curves, the dip in the middle region is more severe for the older group. The older adults also show a much steeper primacy effect. Thus, although older adults tend to recall the first word and last few words as often if not more often than the young adults, age differences are apparent for words presented in the middle of the list. This differentially worse performance on the pre-recency portions of serial position
curves is interesting in light of previous studies. Although there exists a long-standing belief that age selectively affects pre-recency and thus long-term memory (Craik, 1968, 1977), most recent studies have demonstrated a parallel age difference across all portions of the curve (e.g., Kahana, Howard, Zaromb, & Wingfield, 2002; Parkinson, Lindholm, & Inman, 1982; Capitani, Della Sala, Logie, & Spinnler, 1992; Spinnler, Della Sala, Bandera, Baddeley, 1988). The current results fall somewhere in between these two camps.

The fact that older adults perform particularly worse on serial recall tasks could reflect difficulties in two main areas. In general, poor performance during serial recall can result if a participant begins recall with a word appearing late in the list (and thus limits the number of words that can be subsequently recalled in order) and/or fails to encode or retrieve the words in the order in which they appeared. An analysis of the PFR argues convincingly against the first option, as older participants are just as likely to begin recall at the beginning of the list as are the young participants. It seems, then, that the older adults' deficits in order memory are due to poorer temporal organization of the word lists. Age differences in the lag-CRP corroborate this. Older adults show a much weaker forward asymmetry, implying that they are less likely than young adults to recall words in the order that they appeared.

Kahana et al. (2002a) found similar results using PFR and lag-CRP to analyze free recall in young and older adults. They concluded that both age groups initiated recall in the same manner, but the older adults' recall transitions were much less influenced by temporal proximity of the study items. In the present study, these differences were amplified for serial recall. The young adults apparently shifted strategies for serial recall, exhibiting a stronger lag recency effect in addition to initiating recall with earlier items. The older adults successfully altered their strategies for initiating recall to match the task, but unlike the young adults, they did not show a
stronger lag recency effect. These results suggest that the older adults were attempting to follow serial recall instructions, but they were simply less able to temporally organize the word lists.

Poorer temporal organization could certainly account for decreased performance on serial recall, but one would also expect it to affect performance on free recall, since previous studies have demonstrated a positive correlation between temporal organization and free recall performance (Howard, Wingfield, & Kahana, under review). Since the older adults perform free recall almost as well as the young adults, it seems likely that they are using something else, perhaps semantic organization, to compensate for decreased temporal organization. Based on observation and participants' comments, it seems that the older adults prefer to organize recall by conferring semantic connections or categories on the word lists. A recent study by Howard and Kahana (2002b) used quantitative measures of semantic similarity to calculate a different type of conditional response probability curve, the LSA-CRP. By comparing the LSA-CRP with the lag-CRP, they demonstrated that both semantic and temporal factors contribute to recall, although they are differentially affected by certain variables, such as interitem distractors. One variable they did not examine, however, was age. We plan to conduct a similar analysis comparing how the effects of semantic similarity and temporal proximity are affected by age.

Perhaps related to this weakening of temporal context, older adults made significantly more incorrect responses than the young adults, in line with previous findings (see Kausler, 1994, for review). Age differences were particularly apparent in the frequencies of repetitions and prior-list intrusions. Kliewi and Lindenberger (1993) also found that older adults were more susceptible to these intrusions than young adults. These two types of mistakes are similar in that they involve correct semantic memory but incorrect episodic memory. In the case of repetitions, a participant has correctly encoded the word but forgets that he/she has already recalled it. Prior-
list intrusions indicate that a participant remembers learning the word but not the circumstances in which it appeared. As previously noted, it has been well established that older adults have more difficulties with episodic than semantic memory (Backman, Small, & Wahlin, 2001). Incorrect responses can also indicate a lack of inhibition (Burke, Mackay, & James, 2000), indicating that older adults are less able to censor their responses. Although these data are not shown, most incorrect responses came later in output for the older adults. This could also support claims for increased interference with age (see Salthouse, 1991, for a review of interference claims).

In addition to age effects, this study also examined the effects of presentation rate on free and serial recall. In line with previous studies (Glanzer & Cunitz, 1966; Murdock, 1962), presentation rate selectively affected the pre-recency portions of the serial position curve. Increasing the amount of time between the presentation of each word allows for increased rehearsal and thus better performance for early items. Decreasing presentation time has the opposite effect. These effects, however, are dependent on rehearsal strategy. Hockey (1973) compared presentation rate effects on participants who either actively rehearsed or passively viewed lists. He found that increasing presentation rate improved pre-recency performance only for the participants who actively rehearsed; the participants who passively viewed the lists actually showed the opposite effect, benefiting more from the faster rates. In the present study, participants were given no instructions regarding rehearsal, and thus it is possible that certain participants opted to passively view the lists instead of actively rehearsing. If enough participants chose this strategy, the presentation rate effect would have been diminished. Although our rate effects are not as pronounced as in some other studies (e.g., Jackson & Schneider, 1985), this explanation seems unlikely. Rather, the smaller differences in
performance are probably more attributable to our choice of more conservative rates (800, 1200, and 2400 ms) as compared to studies using up to 10 s ISIs (e.g., Jackson & Schneider, 1985).

Although presentation rate significantly affected overall performance, it had similar effects across conditions. Thus, neither the more difficult task of serial recall nor the poorer performance of older adults was differentially affected by rate. The lack of a significant interaction between age and rate is somewhat surprising (cf. Kausler, 1994), especially since both factors have been tied to rehearsal. A study by Jackson and Schneider (1985) found that older adults tend to rehearse less effectively than young adults. They found that both age groups displayed enriched rehearsal with longer presentation rates, but the young adults benefited more during recall from the additional time. As indicated above, the small effect of presentation rate in the present study is likely due to our more conservative choice of presentation rates; had considerably longer presentation rates been chosen, perhaps an age difference would have been revealed.

Additionally, although presentation rate affected overall accuracy and serial position curves, it had negligible effect on PFR and lag-CRP results, and it only trivially affected the frequency of incorrect responses. Therefore, one can conclude that altering the presentation rate during recall tasks selectively affects rehearsal time and thus pre-Recency, and it has the same effect regardless of task or age.

In addition to the above analyses, we plan to conduct an analysis using interresponse times (IRTs) to examine response bursting. These IRTs could be used to create conditional response latency (CRL) curves analogous to the CRP curves that use response probabilities. Since output patterns could be influenced by both temporal proximity and semantic similarity between items, both lag-CRLs and LSA-CRLs could be generated and compared. Although both
younger and older adults show a classic response bursting pattern for categorized lists (Wingfield, Lindfield, & Kahana, 1998), it would be interesting to examine how the two groups organize their output for random word lists.

Episodic recall is but one kind of learning, albeit one of the most widely studied forms. Perceptual learning, although also affected by aging, has received far less attention. If global changes in cognitive function are indeed responsible for age-related declines in episodic memory, perceptual learning should exhibit similar declines. On the other hand, dissociations in learning ability would be more indicative of separable processing systems that are differentially impaired in normal aging. To address the specific issue of perceptual learning in older adults, as well as the extent to which age-related changes in episodic and perceptual learning might be connected, we investigated adaptation to time-compressed speech.

**Experiment 2**

In the course of normal conversation, people continually alter various aspects of their speech, including rate, pitch, tone, and volume. Speech rate in particular is subject to frequent and substantial changes, even by single speakers within a conversation (Miller, Grosjean, & Lomanto, 1984). While most healthy young adults are normally unaware of these variations, older adults frequently complain of difficulties understanding fast speech. Many of these complaints come from adults whose hearing is otherwise excellent: they are capable of hearing and understanding slower speech at the same volume and pitch, but the rapid speech rate alone causes them difficulty. These intuitive observations have been supported by experimental
studies showing that healthy older adults perform differentially worse than their younger counterparts as speech rate increases (Wingfield, Poon, Lombardi, & Lowe, 1985; Wingfield, Tun, Koh, & Rosen, 1999), and that this decline is not solely due to changes in auditory acuity (Gordon-Salant & Fitzgibbons, 1993).

To investigate comprehension of rapid speech, most current studies use computer manipulated time-compressed speech. Using computers to manipulate speech has numerous benefits over having human speakers attempt to naturally change their speech rate. First of all, humans are unable to increase their speech rates to the same extent as is possible using a computer. Computers can also generate time-compressed speech in a quantifiable manner, providing better control over studies. Furthermore, when humans attempt to increase their speech rates dramatically, they distort certain critical aspects of speech, such as the relative duration of words and silences (Lane & Grosjean, 1973). These distortions tend to have an adverse effect on rapid speech comprehension (Janse, 2003). By contrast, computer generated time-compressed speech is produced using a sampling algorithm that deletes small segments from both words and silences at regular intervals. The result is very rapid speech that preserves the normal relative temporal patterns of speech (Foulke, 1971). This method of time-compression is advantageous over other forms of speeding up speech (such as fast playback of recorded speech) in that it maintains normal pitch clarity as well.

An alternative to this method of compression would be to use a so-called nonlinear method of time compression, in which only steady-state portions of words (e.g., extended vowels) are compressed. At the word level, this method of compression can produce greater intelligibility than the uniform compression method (Gordon-Salant & Fitzgibbons, 1993; Janse, 2003). At the sentence level, however, nonlinear compression can distort natural relative
temporal patterns important for syntactic parsing and comprehension (Goldman-Eisler, 1968; Shattuck-Hufnagel & Turk, 1996). Because we wished to preserve these relative temporal patterns, we compressed our sentences using the uniform method.

Artificially time-compressed speech was first studied in the 1950s as a potential educational tool, motivated by the idea that people could devote less time to absorbing the same quantity of information. Researchers found that repeated exposure to rapid speech over the course of days or weeks resulted in increased performance (Orr, Friedman, & Williams, 1965; Orr & Friedman, 1968). Orr and Friedman (1968) found that participants exposed to time-compressed passages for seven hours a day for five days straight showed similar improvement on comprehension tasks to participants exposed to the passages for 1-2 hours per day a few times a week. A number of more recent studies have been devoted to investigating whether comprehension of rapid speech in young adults can improve with short-term practice (e.g., Mehler et al., 1993; Dupoux & Green, 1997). These studies presented participants with 10-20 time-compressed sentences and asked them to write down exactly what they heard immediately following each sentence. Participants’ accuracy improved significantly over this set of sentences (Altmann & Young, 1993; Dupoux & Green, 1997). This improvement was also demonstrated when sentences were composed of non-words (Altmann & Young, 1993) or were presented in an unfamiliar language with similar phonemes (Pallier, Sebastian-Galles, Dupoux, Christophe, & Mehler, 1998; Sebastian-Galles, Dupoux, Costa, & Mehler, 2000). These studies demonstrate that adaptation can occur even when participants do not understand the words and indicate that the adaptation must take place at a pre-lexical level.

While these studies clearly found that young adults could adapt to rapid speech, none of them addressed performance in older adults. It is known that even healthy aging is accompanied
by a general decrease in processing speed (Salthouse, 1996), which may account for older adults’ poorer performance on rapid speech comprehension tasks. Spoken language comprehension is inherently a time-dependent process. Word recognition, syntactic information, and general meaning must be continually updated and integrated as new information arrives. With rapid speech, there is less available total processing time, which presumably makes comprehension increasingly difficult with age. Wingfield et al. (1999) investigated this possibility by inserting pauses at clause and sentence boundaries in time-compressed speech. When the inserted pauses restored the total time to that of uncompressed sentences, older adults’ recall performance was significantly improved, although not to the same extent as that of young participants. Thus, declines in processing time cannot entirely account for the age discrepancy in comprehension of rapid speech. It has been suggested that a decline in processing transient acoustic cues may also be responsible for this discrepancy (Gordon-Salant & Fitzgibbons, 2001).

The fact that perceptual factors play a role in rapid speech comprehension suggests that older adults could improve their performance through perceptual learning. Older adults do demonstrate perceptual learning in other modalities, such as motor learning (e.g., Fernando-Ruiz, Hall, Vergara, & Diaz, 2000). Fernando-Ruiz et al. found that older adults demonstrated similar levels of prism adaptation, although they took longer to adapt than young adults. In a recently conducted study, Peelle and Wingfield (under review) investigated whether this plasticity also occurs in rapid speech comprehension. Participants were presented with 20 time-compressed sentences and asked to recall what they heard immediately following each sentence. Indeed, while the older adults’ performance at a given rate was worse than that of the young adults, the two groups demonstrated similar improvement when matched for starting accuracy. However, in another experiment presenting participants with 40 time-compressed sentences, the older adults’
improvement seemed to level off after 10-20 sentences, while the young adults continued to improve (Peelle & Wingfield, under review). Peelle and Wingfield also found another interesting age-related difference. After adapting to sentences presented at a very fast rate, young adults were able to transfer this perceptual learning to sentences presented at a moderately fast rate, performing significantly better than they had during their initial pre-adaptation exposure to this rate. The older adults, however, did not demonstrate this transfer.

This inability of older adults to transfer perceptual learning to different speech rates could have important applications. In everyday conversations, we must adapt to continually changing speech rates. While the idea that older adults can adapt to rapid speech is certainly promising, it would be useless if the older adults could not apply this learning to multiple rates. To investigate the effects of mixed rates on adaptation to rapid speech, Dupoux and Green (1997) presented young participants with a block of 5 slower sentences following a block of 10 very fast sentences. The participants were then presented with 5 more sentences at the very fast rate. Although there was a brief drop in fast sentence recall accuracy immediately following presentation of the slower sentences, the interruption did not have a lasting effect on performance. Peelle and Wingfield’s findings regarding age-related rate transfer discrepancies suggest that this may not be the case with older adults. Additionally, the participants in the Dupoux and Green study had already had sufficient exposure to the very fast sentences to adapt to them. With other sensory modalities, adaptation can only occur with constant exposure to a specific stimulus; intervening exposure to stimuli varying along the same dimension disrupts this adaptation. It would thus be interesting to investigate whether adaptation to rapid speech is likewise affected by intervening slower speech during the adaptation period.
Although Dupoux and Green tested only young adults, Sommers (1997) tested both young and older adults in a study assessing how variability of speech rate affects comprehension. Participants were asked to listen to a series of monosyllabic words and identify each one as it was presented. Words were presented at one of three speech rates, recorded by human speakers naturally altering their speaking rate. Participants heard lists composed of all fast, all medium, or all slow words (single-rate lists) or lists varying between the three rates (mixed-rate lists). Both young and older participants performed significantly worse on mixed-rate lists than on single-rate lists. Although the older adults had more difficulty with faster rates, they did not perform differentially worse on the mixed rates per se. Whereas Sommers’ study addressed speech comprehension on the word level, the present study aims to extend these findings to examine the effects of mixed-rate speech on sentence comprehension and adaptation to artificially time-compressed speech.

In the current study, adaptation to time-compressed speech is analyzed under four conditions. The “normal” condition replicates one of the Peelle and Wingfield experiments, presenting participants with 20 compressed sentences. In the “alt-1” condition, uncompressed sentences alternate every other sentence with the compressed sentences. The “spaced” condition consists of only compressed sentences, with sentence-length pauses inserted between each. If adaptation is affected by interruptions, it is important to determine whether this interference is caused by exposure to different speech rates or to no speech at all. Finally, the “alt-4” condition consists of compressed and uncompressed sentences presented alternatively in blocks of four sentences. Since exposure to four compressed sentences is sufficient to induce adaptation (Peelle & Wingfield), this condition is similar to the mixed-rate experiment of Dupoux and Green.
(1997). The effects of normal adult aging (healthy and minimal hearing loss) are examined under each of these four conditions.

Method

Participants. There were 16 participants in the younger group and 15 in the older group. The younger group (8 men and 8 women) was composed of Brandeis University undergraduates aged 18-22 ($M = 19.6$, $SD = 1.8$). They had a mean of 14 years of education at the time of testing ($SD = 1.3$) and a mean WAIS vocabulary score of 47.2 ($SD = 5.2$). They had a mean forward digit span of 8.1 items ($SD = 0.9$) and a mean backward digit span of 5.9 ($SD = 1.2$).

The older group (6 men and 10 women) was composed of community-dwelling adults aged 65-85 ($M = 72.4$, $SD = 5.0$). They had a mean of 15.8 years of education ($SD = 1.4$) and a mean WAIS vocabulary score of 49.1 ($SD = 7.2$). Their mean forward digit span was 7.6 items ($SD = 1.1$), and their mean backward span was 5.9 ($SD = 1.5$).

Both groups were thus well-educated, with the older group having an average of 1.8 more years of formal education, $t(30) = 3.74, p < .001$. The two groups were statistically equivalent in tests of vocabulary, $t(30) = 0.84$, n.s., forward digit span, $t(30) = 1.44$, n.s., and backward digit span $t(30) = 0.13$, n.s. All participants were native English speakers and reported themselves to be in good health. They were compensated with a small monetary sum for their participation.

Audiometric tests were used to ensure that all participants had good hearing for their ages. The mean pure-tone average (PTA; taken as the mean threshold for tones at 500, 1000, and 2000 Hz) in the better ear was 3.5 dB ($SD = 3.6$) for the younger group and 13.7 dB ($SD = 8.2$) for the older group. Mean speech reception thresholds (SRTs; the threshold at which two-syllable words can be correctly identified 50% of the time) for the better ear were 4.4 dB ($SD =
2.5) for the younger group and 12.8 dB (SD = 8.4) for the older group. Although age differences in both PTA, \( t(30) = 4.54, p < .001 \), and SRT, \( t(30) = 3.89, p < .001 \), were significant, both groups fell within the range of clinically normal hearing, defined as a PTA of 25 dB or less in the speech frequency range (Hall & Mueller, 1997).

**Stimuli.** Stimuli were 136 sentences specially constructed for this study. Each sentence contained 10 words (7 content words and 3 function words) and 14-16 syllables. (See Appendix for a list of stimuli sentences.) Sentences were recorded by a female native American English speaker at a comfortable rate of approximately 200 words per minute (wpm). Sound-editing software (SoundEdit 16, Macromedia, Inc., San Francisco, CA) was used to compress 96 of these sentences to 30\% of their original duration (approximately 680 wpm) for the young group and 40\% of their original duration (approximately 510 wpm) for the older group.\(^2\) Sentences were compressed using the uniform sampling technique, in which short segments of speech and silence are removed at regular intervals (Faulke, 1971). The remaining 40 sentences were left uncompressed. The compressed sentences were divided into four sets of 24, and the uncompressed sentences were divided into two sets of 20. Within each set the order of sentences was randomized for each participant. Sentences were presented biaurally over headphones.

**Conditions.** Four presentation conditions were used in this study. In each of the four conditions, the first two sentences (referred to as PRE) and last two sentences (POST) were always presented at the compressed rate. The sentences in between varied in compression rate according to condition: Normal consisted of 20 compressed sentences presented consecutively, Alt-I was 20 compressed sentences alternating every other sentence with 20 uncompressed

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\(^2\) Because older adults' comprehension of very rapid time-compressed speech is much worse than that of young adults (e.g., Wingfield, Poon, Lombardi, & Lowe, 1985; Wingfield, Tun, Kok, & Rosen, 1999), we chose to give them a slower rate to match the two groups for starting accuracy, following the Peelle and Wingfield (under review) approach.
sentences, *Alt-4* was 20 compressed sentences alternating in four-sentence blocks with 20 uncompressed sentences, and *Spaced* was comprised of 20 compressed sentences presented with 5 s delays between each. Figure 5 illustrates the four conditions.

![Diagram](image)

**Figure 5.** Schematic illustrating the spacing of compressed and uncompressed sentences for the four conditions.

*Procedure.* Participants participated in four separate sessions of about 15-20 minutes each. Each session involved one of the four conditions described above. The order of these conditions was counterbalanced across participants. Each condition used one of the four lists of compressed sentences, also counterbalanced across participants. The sessions occurred 7-8 days apart to minimize possible carryover in learning from the previous session.

At the start of each session, participants were seated at a computer and given instructions. The first session involved one practice sentence to orient participants to the task, but the three subsequent sessions involved no practice. Participants were cued to press a key to hear the first sentence. Immediately after hearing the sentence, participants were instructed to recall verbatim
as much of the sentence as possible. They were encouraged to guess if they were unsure, and they were informed that there would be no penalty for words recalled incorrectly or in the wrong order. Participants pressed a key to indicate when they were finished recalling, and then received another cue to press a key to hear the next sentence. Participants’ spoken responses were recorded onto a cassette tape using a lapel microphone.

**Analyses.** Sentence recall was scored as the number of correct content words out of seven possible for each sentence. Order of recall was ignored – as long as the participant recalled a content word heard in the sentence, it was counted as correct. Words with added or eliminated suffixes (e.g., -s, -ed, -ing) were counted as correct, as were verbs given in the wrong tense. If a participant recalled half of a compound word (e.g. “school” instead of “schoolwork”) it was marked as half credit. Portions of non-compound words (e.g. “let” instead of “letters”) were not given any credit.

All results focused on performance on compressed sentences. Intervening uncompressed sentences were ignored, and percentage correct was blocked into trials of two compressed sentences each. Thus, each condition consisted of PRE, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and POST. The difference between PRE and POST is assumed to represent the overall improvement that occurred during the session.

**Results**

The upper panels of Figure 6 show the accuracy during PRE and POST as a function of learning condition. The upper left panel gives performance for the young adults, who heard sentences at a rate compressed to 30% of the original rate (approximately 680 wpm). The upper right panel gives performance for the older adults, who heard sentences at a rate compressed to
40% of the original rate (approximately 510 wpm). Due to the slower speech rate, the older adults both started and ended at slightly higher levels than the young adults. On average, the young group improved from 25.1% correct to 39.8% correct, an average improvement of 14.7% per session. The older group improved from an average of 29.0% correct during PRE to 50.7% correct during POST, an average improvement of 21.7% correct per session.

**Figure 6.** Average performance of young and older adults on the PRE and POST blocks for each condition (top row, collapsed across week) and week (bottom row, collapsed across condition). Error bars represent 1 SE.

As was our intent, the PRE levels across condition and age group were approximately equal. The data were submitted to a 4 (PRE: Normal, Alt-1, Alt-4, Spaced) X 2 (Age: Young,
Older) mixed design ANOVA, with PRE as a within-participants variable. The main effect of PRE was not significant, $F(3,90) < 1$ ($MSE = 233.490$), as expected from the counterbalancing design. There was also no significant main effect of Age, $F(1,30) < 1$ ($MSE = 1364.581$) or Age X PRE interaction, $F(3,90) < 1$ ($MSE = 233.490$), supporting the use of slower speech rates to equate the two age groups for starting accuracy.

The data were also submitted to a 4 (POST: Normal, Alt-1, Alt-4, Spaced) X 2 (Age: Young, Older) mixed design ANOVA, with POST as a within-participants variable. There were no significant main effects of POST, $F(3,90) < 1$ ($MSE = 297.414$) or Age, $F(1,30) = 2.44$ ($MSE = 1566.578$), nor was there a significant Age X POST interaction, $F(3,90) < 1$ ($MSE = 297.414$), indicating that both age groups adapted to the rapid speech equally well in all four learning conditions.

The lower panels of Figure 6 show PRE and POST accuracy as a function of week, with data collapsed across condition. Visual examination of the lower left panel suggests that the young adults begin at an increasingly higher performance level each week, indicative of a clear carryover in learning from week to week. The older adults, on the other hand, do not show this same steady carryover pattern. While they make a jump in performance level from PRE of the first week to PRE of the second week, they do not retain any additional learning between weeks 2 and 3 or weeks 3 and 4.

The data were submitted to a 4 (PRE: Week 1, Week 2, Week 3, Week 4) X 2 (Age: Young, Older) mixed design ANOVA, with PRE as a within-participants variable. The main effect of PRE was significant, $F(3,90) = 5.29$, $MSE = 194.427$, $p < .005$, indicating that participants do retain a certain degree of learning from week to week. Despite the age group
differences apparent on inspection, there was no significant main effect of Age, $F(1,30) < 1$ ($MSE = 1364.581$) or Age X PRE interaction, $F(3,90) < 1$ ($MSE = 194.427$).

To compare the POST levels of performance after each week, a 4 (POST: Week 1, Week 2, Week 3, Week 4) X 2 (Age: Young, Older) mixed design ANOVA was performed with POST as a within-participants variable. The POST levels across age group and week were relatively stable, indicated by a lack of significance in the main effects of POST, $F(3,90) = 2.48$ ($MSE = 262.532$) and Age, $F(1,30) = 2.44$ ($MSE = 1566.578$), and in Age X POST interaction, $F(3,90) = 1.84$ ($MSE = 262.532$).

Figure 7 displays performance over the entire learning period for the two age groups. Each point represents the average percent correct for a trial block of two compressed sentences (PRE, POST, and the 10 intervening trial blocks). Power functions were fit to the data to illustrate the general shape of the learning; improvement occurs more rapidly for the first few trials, then gradually levels off. The equations for the power functions are given at the bottom of each plot. Power functions take the form of $y=ax^b$, where $a$ represents the starting accuracy level and $b$ represents the steepness of the curve (larger values of $b$ indicate more improvement).
The upper panels of Figure 7 show learning as a function of the four conditions. The data were submitted to a 12 (Trial: 12 blocks of 2 sentences) X 4 (Condition: Normal, Alt-1, Alt-4, Spaced) X 2 (Age: Young, Older) mixed design ANOVA, with Trial and Condition as within-participants variables. The main effect of Trial was significant, $F(11,330) = 11.72$, $MSE = 341.285$, $p < .001$, verifying that participants did improve over the course of the session. There were no significant main effects of Condition, $F(3,90) < 1$ ($MSE = 767.027$), or Age, $F(1,30) < 1$ ($MSE = 16507.418$), indicating that similar levels of performance and learning took place regardless of age or learning condition. This was supported by a lack of Trial X Age interaction,
\[ F(11,330) < 1 \ (MSE = 341.285), \] Condition X Age interaction, \[ F(390) < 1 \ (MSE = 767.027), \]
Condition X Trial interaction, \[ F(33,990) = 1.14 \ (MSE = 346.277), \] and Condition X Trial X Age interaction, \[ F(33,990) = 1.12 \ (MSE = 346.277). \]

Performance over the four weeks is shown in the lower half of Figure 7. Both improvement within sessions and carryover between them are visually apparent. In addition to having a higher starting level each week, the young group appears to re-learn more quickly each week, as evidenced by increasingly flatter power functions. That is, although approximately equal levels of improvement are achieved each week, the bulk of the learning occurs over fewer sentences, thus exerting less influence on the best-fit power functions. While Week 1 sees a fairly steady increase across the learning period, Week 4 consists of an immediate jump between the first two trial blocks, after which very little additional improvement can be seen. On the contrary, while the older group clearly demonstrates improvement within each session, there is no clear pattern regarding week-to-week carryover in starting level or re-learning rate.

To test these observations, a 12 (Trial: 12 blocks of 2 sentences) X 4 (Week: Week 1, Week 2, Week 3, Week 4) X 2 (Age: Young, Older) mixed design ANOVA was conducted with Trial and Week as within-participants variables. As expected, there was significant improvement within sessions, as confirmed by a main effect of Trial, \[ F(11,330) = 11.72, \ MSE = 341.285, p < .001. \] Week-to-week differences were also important; there was both a significant main effect of Week, \[ F(390) = 22.53, \ MSE = 425.839, p < .001, \] and a significant Week X Age interaction, \[ F(390) = 4.02, \ MSE = 425.839, p < .01. \] There was, however, neither a significant main effect of Age, \[ F(130) < 1 \ (MSE = 16507.418), \] nor Trial X Age interaction, \[ F(11,330) < 1 \ (MSE = 341.285), \] demonstrating that age differences were only reliable regarding week-to-week carryover of learning, as suggested by Figure 7. Finally, the Week X Trial, \[ F(33,990) < 1 \ (MSE = 346.277). \]
= 349.582), and Week X Trial X Age, \(F(33,990) = 1.04\) (\(MSE = 349.582\)), interactions were not significant, implying that improvement within sessions was relatively consistent across age groups and weeks.

All of the above analyses were based on data reflecting average percent correct. Because the sentences displayed a large degree of variation in difficulty, individual scores were expressed as z-scores in addition to percent correct. The z-score data strongly resembled the percent correct data, so separate analyses were not included.

**Discussion**

The results from this experiment clearly indicate that within a given session, older adults were capable of learning to comprehend time-compressed speech as well if not better than young adults when equated for starting accuracy. Although older adults generally have poorer comprehension of time-compressed speech than the young at a given rate (e.g., Wingfield, Poon, Lombardi, & Lowe, 1985; Wingfield, Tun, Koh, & Rosen, 1999), the present study demonstrates that if they are given a slightly slower rate to match for starting accuracy, older adults demonstrate similar degrees of improvement with repeated exposure to time-compressed speech. Both age groups in this study showed increases in recall accuracy of approximately 15-20% after listening to and recalling 24 time-compressed sentences. This range of improvement is very much in line with previous studies examining adaptation to time-compressed speech (e.g., Peele & Wingfield, under review).

One major difference between this study and previous studies is that the present study examined learning over a series of four separate sessions spaced one week apart, whereas most previous studies involved single learning sessions. The recent Peele and Wingfield (under
review) study found that young adults showed a greater carryover in learning when tested for recall accuracy approximately ten minutes after initial exposure to time-compressed speech. The present study addressed that finding, supporting the idea that there are significant age differences regarding carryover between sessions. The young group showed steady week-to-week improvement in both baseline level and rate of learning, whereas the older group showed no consistent trends for either measure of carryover. Despite the lack of a clear trend, however, the older adults did seem to improve in baseline level between the first and second sessions, and their performance during Week 1 was lower than during the subsequent weeks. The fact that the young group continued to improve week after week indicates a consistent retention of learning over long-term periods. This age-associated disparity could be indicative of a more generalized pattern of aging – that short-term learning may remain intact while long-term learning deteriorates, a hypothesis that warrants further investigation.

In addition to comparing adaptation to time-compressed speech spaced over the course of weeks, the present study also compared within-session adaptation occurring for the different learning conditions. Similar levels of improvement were found for all conditions, indicating that improved recall accuracy occurs whenever participants actively listen to rapid speech. Intervening uncompressed sentences or pauses had no significant effect on overall improvement, suggesting that total amount of exposure to time-compressed speech is the driving factor for this adaptation. The ‘alt-1’ condition, which had a slow sentence following every fast sentence, did not seem to prevent or slow the normal learning from taking place, and the ‘alt-4’ condition, which had a block of four slow sentences after every block of four fast sentences, did not cause sufficient “forgetting” to affect the overall improvement.
These results are in line with previous literature on adaptation to mixed-rate speech. Dupoux and Green (1997) conducted a study similar to our ‘alt-4’ condition and found that while the intervening slower sentences produced a brief drop in performance, participants quickly recovered to achieve normal levels of improvement. In fact, a closer examination of the ‘alt-4’ panel of Figure 7 reveals that the noisiness of the data may actually be due to quick drops and recoveries over the course of the learning interval. The fact that certain conditions resulted in less noisy data over the course of the session than others suggests that they may be more naturally suited for this type of learning, although equal levels of improvement were ultimately obtained regardless of condition. It is true that Sommers (1997) found that both young and older adults showed poorer comprehension on mixed-rate word lists than on single-rate lists, suggesting that overall performance on our two mixed-rate lists (‘alt-1’ and ‘alt-4’) should have been lower than performance on the two single-rate lists (‘normal’ and ‘spaced’). The fact that performance in this study on all four lists was roughly equal for both age groups is probably due to differences in stimuli (words versus sentences) and technique (fast talking humans versus computer-generated compression).

This lack of an improvement difference based on learning condition was found in both age groups. This implies that a high degree of plasticity is still present in the aging brain. Not only can older adults adapt to this very difficult stimulus in isolation, they are capable of adapting just as well to the fast sentences when slow sentences are mixed in. Furthermore, when they are equated for starting accuracy, their overall levels of improvement are as high if not higher than those of the young adults.

Unfortunately, compared to the young adults, older adults’ comprehension of rapid speech is sufficiently worse to necessitate using a slower rate as the test stimulus. Had the older
adults been presented with the young group rate, it would have been too difficult, and the majority of them would have understood nothing. Giving the young group the older group rate would have had the opposite effect, with most young adults quickly achieving perfect comprehension of the sentences, preventing any comparison of learning condition (see Peelle & Wingfield, under review). Separate speech rates were thus chosen to yield approximately equal baseline levels of accuracy. Using similar speech rates, Peelle and Wingfield ran three groups of participants: an older group receiving a slower rate, a young accuracy-matched group receiving a faster rate, and a young rate-matched group receiving the slower rate. They found that young adults showed more improvement with repeated exposure to the slower rate (approximately 25% improvement) than to the faster rate (approximately 20% improvement). This small rate-associated difference could account for why the older adults in the present study appear to improve more than the young adults.

Overall, other than a general decreased comprehension of rapid speech with age, the only age-related problem was a lack of consistent carryover in learning between sessions. The older adults performed equally well with respect to short-term adaptation to rapid speech in all learning conditions. When equated for starting accuracy, age differences only became apparent on assessments of long-term retention and re-learning on the order of weeks.

**General Discussion**

The results from these two experiments clearly demonstrate that cognitive abilities are not uniformly affected by aging. Although older adults generally do poorer on cognitive tasks, examining overall performance rarely gives an accurate picture of cognitive aging. While certain
specific abilities are severely impaired in older adults, other abilities show no age difference whatsoever. Thus, one must be careful not to over-simplify such large, complicated domains as memory and learning.

Experiment 1 explored age-associated problems with episodic memory. Overall, older adults recall fewer words than young adults in every condition, with the most severe age differences appearing when order information is taken into account. A number of analyses suggest that order information is so greatly affected because older adults have more difficulty establishing or maintaining temporal connections between items. Thus, while they may remember certain items, they may not remember where in the list those items appeared, or even whether those items appeared in the most recent list or belonged to a previous list.

Moderate age differences exist for recall of items appearing in the early-to-middle portions of a list. These are the items that must be rehearsed or encoded into long-term memory for successful retrieval. As previously discussed, a vast array of hypotheses have attempted to explain this deficit, including reduced processing resources (Foos, 1989), poorer organization (Tulving, 1962), and increased interference (Salthouse, 1991).

Other aspects of episodic memory remain completely unaffected by age. Older adults remember very recent items just as well as young adults. They are also affected in the same way as young adults by changes in presentation rate, showing increased performance with longer presentation rates and decreased performance with shorter rates. If performance were simply averaged across serial position and condition, these intact abilities would be concealed.

A similar range of ability and disability was found in Experiment 2, which examined perceptual learning for time-compressed speech. In general, the most severe age-related problem was in simply comprehending the very rapid speech. Evidence from previous studies indicated
that this deficit was large enough to warrant using different speech rates for the two age groups to compare learning patterns.

When the older adults are equated for starting accuracy, they show a moderate deficit in long-term carryover of learning. Older adults do not show a consistent increase in either baseline ability or rate of re-learning from week to week. Young adults demonstrate clear patterns of improvement for both of these measures.

Although long-term perceptual learning is affected by age, short-term learning is not. Older adults are just as capable of adapting to very rapid speech as their young counterparts. As long as they are equated for starting accuracy, similar levels of improvement are achieved. Additionally, both young and older adults alike are able to achieve these same levels of improvement when slower speech is mixed in at different intervals in an unsuccessful attempt to interrupt the learning process.

In summary, within both memory and learning there exists a large gradient of age-related deficits. We have demonstrated here how a combination of preserved, mildly affected, and severely affected cognitive abilities result in an overall picture of moderate cognitive decline with age. We would argue that in order to fully understand the general processes underlying cognitive aging, one must first understand these specific deficits and preservations and how they are associated. This thesis represents the beginning of such an attempt.

References


Peelle, J. E. and Wingfield, A. (under review). Dissociations in Perceptual Learning Revealed by Adult Age Differences in Adaptation to Time-Compressed Speech.


Appendix

All stimuli sentences from Experiment 2 are listed below. Each sentence contains 7 content words and 3 function words. The function words are italicized and were ignored for analyses.

1. Jacob washed his convertible and applied hot wax and paint.
2. Julie believes the new orange sweater looks good on her.
3. Susan angrily washed the dirty dishes after she came home.
4. The bumblebee found the colorful flower and drank sweet nectar.
5. Sally asked her friendly neighbor for the big red shovel.
6. The ambitious coach thought her team deserved a gold medal.
7. The very agile gymnast could perform cartwheels and back flips.
8. The sick little boy with chicken pox was highly contagious.
9. The student who wrote the best essay received great rewards.
10. The important meeting that lasted too long was very helpful.
11. Robert thinks his baseball team will win the annual tournament.
12. The awkward teenager who broke his leg must use crutches.
13. The teacher believes that hard work makes a student smarter.
14. The secretary made phone calls and sent letters to customers.
15. The carpenter often fixed broken rocking chairs with his hammer.
16. The doctor who saw the sick patient prescribed expensive medicine.
17. Rachel likes to eat strawberry ice cream in the afternoon.
18. The eager reporter took detailed notes at the press conference.
19. The talented artist carved a large ice sculpture that melted.
20. The old house had missing tiles and numerous ceiling holes.
21. Sarah went to the variety store to find comic books.
22. The tragic forest fire destroyed a vast plot of land.
23. The police officer who arrived first saw the criminal leave.
24. The angry lion attacked the small quick mouse that ran.
25. The banker easily opened checking accounts for his new customers.
26. Brenda told her little sister to enjoy the good weather.
27. Michael went to the grocery store to buy fresh fruit.
28. The cute little puppy that played fetch was very adorable.
29. The successful college students can take notes and pay attention.
30. The photographer knows his models need time to dress nicely.
31. The lively frog happily jumped into the cool bubbling stream.
32. The tired employee brought his boss the requested blank forms.
33. The expert sandwich maker could prepare turkey and cheese subs.
34. The delighted father hoped his daughter won the grand prize.
35. The talented gymnast who learned new skills practiced her routine.
36. The mountain guide built a large cooking fire that glowed.
Young girls happily write in their diaries with colorful pens.
Arthur built a large wooden bookshelf for the living room.
The teacher thinks his students need repetition to learn well.
The happy bride gave her husband an expensive wedding gift.
The friendly dentist helped her patients preserve their white teeth.
The family that saved water survived the long hot drought.
The lazy worker who sets his own hours left early.
Brian read the long novel and wrote a short summary.
Hannah drove to the department store and purchased new blouses.
The medical student thought that schoolwork would replace leisure time.
The new mailman delivered the letters to every resident.
The candidate who gave the best speech became town mayor.
Kathy wrote a long poem about her first love interest.
Wendy stopped by her friend's house to return several items.
Sharon took her dirty work clothes to the neighborhood cleaners.
The magician sometimes played practical jokes on his close friends.
The critic claimed that the new book included flat characters.
The strong mountain climber scaled the steep rock without falling.
Jackie saw the former baseball star driving slowly by her.
The author quickly wrote long novels with his new computer.
The generous son gave his mother a thoughtful birthday present.
The talented young singer could perform jazz or opera music.
Denise planned a fun evening after her new boyfriend called.
Justin left the movie theater before the bad show ended.
The broker never made shady business deals with his clients.
The runner who drank water won the long difficult race.
The janitor slowly washed tile floors for the big company.
Jamie wrote a paper that discussed modern art and culture.
The baker knows that bread requires yeast to rise properly.
The storm that began suddenly brought winds and heavy rain.
The woman ordered large cheese pizzas for her hungry children.
Gary quickly raked the fallen leaves before the storm came.
The busy librarian put reference books on the wrong shelf.
Happy couples lay on the crowded beach on sunny days.
The experienced potter made a small clay pot that cracked.
The bright young lawyer argued the difficult case without help.
The helpful janitor stored old chairs in the empty closet.
The river that flowed quickly carried sailboats and merchant ships.
Becky made the coffee and added skim milk and sugar.
The college graduate grew a mustache to look more mature.
The waitress thought that the diner needed more coffee mugs.
The rock star attended parties where he knew many people.
Steven believes his mother's former job was bad for her.
The company president held weekly meetings in the large room.
The reckless driver who changed lanes blindly caused the accident.
The young athlete who won the big tournament practices daily.
The woman happily baked fresh raisin bread for the party.
Marie ate a sandwich that contained peanut butter and jelly.
The clever salesman who managed the account made large profits.
The director thought that the movie needed better action scenes.
The rich musician bought his girlfriend diamond necklaces and rings.
Laura placed the ripe yellow bananas on the kitchen table.
The man who sat silently heard rumors and important secrets.
The famous author knew her novel reached a wide audience.
The doctor knows that people need exercise to stay healthy.
The obedient dog that chased its tail ate table food.
The doctor who performed the heart surgery earned wide acclaim.
The aspiring young actress wanted to become rich and famous.
The young musician played the flute and sang beautiful music.
Light rain gently falls on the forest during summer days.
The statue made of solid marble outweighed the brick house.
The baseball player who batted last scored the winning run.
Carol removed her wet mittens and found a warm sweater.
The local barber who owns his business purchased new scissors.
Allen dusted the old furniture and mopped the dirty floor.
The chef denied that her potatoes contained too much pepper.
The detective who ran quickly caught the evasive jewel thief.
The short athlete who ran very fast was especially tired.
Melissa took her frisky new puppy for a long walk.
Heavy snow often falls in the mountains during winter months.
The devoted gardener who planted new flowers watched them grow.
The young artist who won the annual award paints well.
The chef who won the cooking awards prepared delicious steak.
The successful lawyer who won many cases was very rich.
The knowledgable farmer thought that rain might fall Tuesday morning.
The construction worker with much experience built the new bridge.
Jenn made a cake and substituted light margarine for butter.
The pretty nurse who treats sick patients wanted to help.
Kara quickly cleaned the whole house before she ate dinner.
The teacher gave a short lecture and assigned tonight's homework.
The new neighbor who threw large parties was very friendly.
The famous actor easily rehearsed for the new action movie.
David baked a chocolate chip cake for a birthday party.
Jessica cooked a large meal and washed the dirty dishes.
Jane grumpily began her homework when the funny movie ended.
The new babysitter nervously looked for the sneaky young boy.
The singer tuned her old guitar and played difficult songs.
Ben walked to the international room to meet exchange students.
The hungry lioness stalked big game on the African plain.
Mary listened to the radio to hear popular new songs.
The cute kitten happily played with the long curtain tassel.
Emily bought the same bathing suit as her twin sister.
Janet easily read the children's novel as she watched TV.
Lauren called her best friend when her favorite pet died.
Christina bought a new car when she earned enough money.
The smiling child opened many presents at her birthday party.
Jasen took his little sister's stuffed animal from her bed.
Seth packed a large picnic lunch for the hiking excursion.
The team's best runner finished the challenging race with ease.
Helen sold the warm brownies at her brother's soccer game.