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Implications of aging, lexicality, and item length for the mechanisms underlying memory span

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Hulme, Maughan, and Brown (1991) provided evidence that the contribution of long-term memory to memory span performance was additive to the contribution of rehearsal rate (e.g., Baddeley, 1986). The present study further explored the relationship between these two contributions in younger and older adults. Speech rates and spans for short, medium, and long words and nonwords were obtained from subjects. Older adults had slower speech rates and smaller spans than did younger adults. Both groups' data were fit well by linear functions relating speech rates to spans. However, the slope of the function that relates speech rate to memory span was greater for words than for nonwords. This finding supports the idea that long-term memory, as well as rehearsal rate, contributes to span performance, and that this contribution is not simply additive.

Memory span is an estimate of the number of items that a person can encounter once and recall accurately. Although this task seems rather simple, understanding the mechanisms that drive performance on span tasks and how span may be related to other cognitive tasks, such as language comprehension, has proved to be anything but simple (see, e.g., Brooks & Watkins, 1990; Craik, 1971; Martin, Shelton, & Yaffee, 1994; Watkins, 1977). The present research is directed at the first of these challenging questions: What are the cognitive processes that underlie memory span? In addressing this question in the present study, we investigated the performance of healthy older adults as well as healthy younger adults. The motivation for exploring the performance of older adults is twofold: (1) any proposed memory mechanisms need to be able to account for data from late as well as early adulthood, and (2) for reasons discussed below, the performance of older adults may be particularly revealing regarding the mechanisms that underlie memory span performance.

Phonological Rehearsal Process Contribution

A phonological rehearsal process—namely, the phonological loop portion of Baddeley's working memory model (Baddeley, 1986, 1990)—is widely assumed to underlie memory span performance. The phonological loop has two components: the phonological store and the articulatory control process. Items to be remembered for a memory span task are entered into the phonological store, which will hold them for roughly 2 sec before they decay. This decay can be postponed by the articulatory control process, which reads information from the phonological store, refreshes it, and returns it to the store. It is assumed that the faster that items can be articulated, the faster they can be refreshed. Faster refreshing means that more items can be refreshed before the trace fades; thus, items that can be articulated faster result in higher spans. For example, short words can be articulated faster than long words, and people have larger spans for short than for long words (the word length effect; Baddeley, 1986, 1990; Baddeley, Thomson, & Buchanan, 1975). Moreover, groups of people who articulate relatively quickly (e.g., young adults) have larger spans than do groups that articulate relatively slowly (e.g., children, Hulme, Thomson, Muir, & Lawrence, 1984; older adults, Kynette, Kemper, Norman, & Cheung, 1990). This relatively simple relation between articulation rate and span can be characterized by the following equation: span = (rate of articulation)(trace duration) + a constant, or $s = rt + c$ (Baddeley et al., 1975; Schweickert & Boruff, 1986). This will henceforth be referred to as the *speech rate–span relationship*.

Although there is a great deal of evidence supporting the idea that a phonological rehearsal process underlies memory span performance (e.g., Baddeley, Lewis, & Vallar, 1984; Baddeley et al., 1975; Hulme et al., 1984; Naveh-Benjamin & Ayres, 1986), there is also growing evidence that this may not be the sole process underlying span (e.g., Besner & Davelaar, 1982; Bourassa & Besner, 1994; Brooks

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& Watkins, 1990; Cowan et al., 1994; Hulme, Maughan, & Brown, 1991). The present study focuses on the possibility that long-term memory may also contribute to memory span performance.

Long-Term Memory Contribution

The idea that long-term memory may contribute to performance on a memory span task is not new (see Craik, 1971; Watkins, 1977). What is new, however, is the attempt to understand how long-term memory would contribute to span performance in terms of Baddeley's model of working memory (1986, 1990). This influential model can account for much of the memory span data in the literature. Thus, until a more powerful model is proposed, it seems reasonable to try to understand the contribution of long-term memory in terms of the Baddeley model. This approach has been used by Hulme et al. (1991), who recently reported two experiments in which they explored the contribution of long-term memory to span performance.

Hulme et al. (1991) investigated people's speech rates and memory spans for words and nonwords. They showed that even when words and nonwords were articulated at the same rate, and thus presumably rehearsed at the same rate, people had higher spans for words than for nonwords. In their second experiment, they showed that learning the translations of words in a second language increased spans for those words, even though the speech rates were not affected by the translation learning. Hulme et al.'s data cannot be accounted for solely by a phonological rehearsal process like the phonological loop portion of Baddeley's working memory model (1986, 1990). If that were the only mechanism underlying span performance, the results of their first experiment should have indicated that spans for words and nonwords were the same because the items were rehearsed at the same rate. An analogous argument can be made regarding the pre- and posttranslation learning span tests in their second experiment. Thus, Hulme et al. suggested that long-term memory also contributes to memory span performance. In a similar investigation with 6- and 10-year-olds, Roodenrys, Hulme, and Brown (1993) found greater spans for words than for nonwords that could not be accounted for by differences in speech rate alone. Roodenrys et al. (1993) also concluded that long-term memory contributes to memory span performance.

Although the Hulme et al. (1991) and Roodenrys et al. (1993) studies suggest that long-term memory can contribute to memory span performance, further investigation of this finding is needed. One important unresolved question is whether long-term memory makes a separate, additive contribution to that of the phonological rehearsal process or whether the contribution of long-term memory is more complicated than that. Consider the Hulme et al. (1991) data. In their first experiment, Hulme et al. found that the slopes of the speech rate–span relationship did not differ for words and nonwords (see Figure 1A). The function for the words simply had a higher intercept. Thus, the data suggested that the contribution of long-term memory, as seen in the higher intercept, was additive to that of the

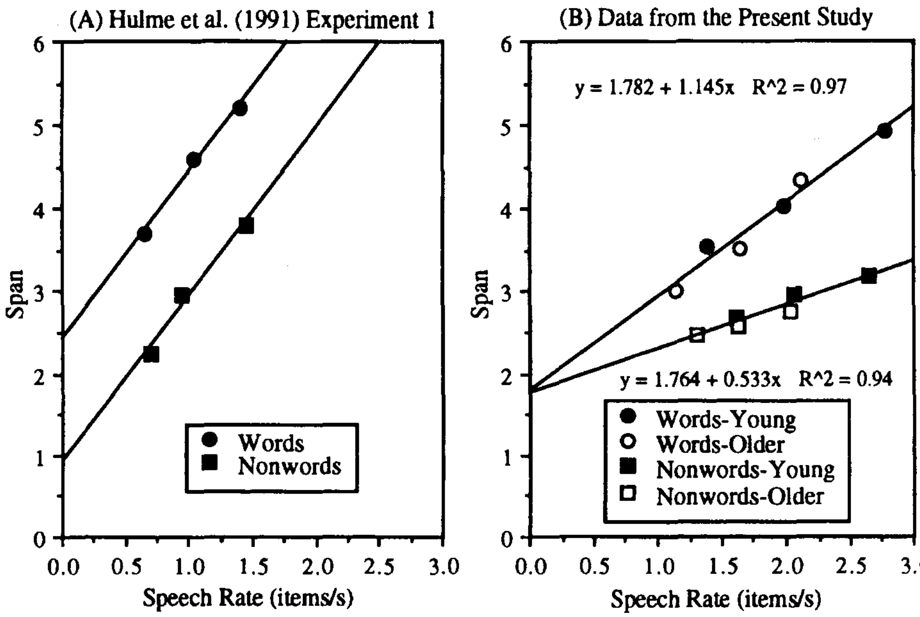

Figure 1. (A) The Hulme et al. data are from "Memory for Familiar and Unfamiliar Words: Evidence for a Long-Term Memory Contribution to Short-Term Memory Span," by C. Hulme, S. Maughan, and G. D. A. Brown, 1991, *Journal of Memory & Language*, *30*, p. 690. Copyright 1991 by Academic Press. Adapted with permission. (B) Regression of cumulative spans onto speech rates (pair rate measures). Filled symbols, younger adults; open symbols, older adults. For both age groups on words and nonwords, the leftmost points are long items, the middle points are medium items, and the rightmost points are short items.

rehearsal process, as seen in the slope across word lengths. In contrast, in their second experiment, Hulme et al. found that the slope of the speech rate–span relationship was steeper at pretranslation learning (no long-term memory representations) than at posttranslation learning (long-term memory representations available). These data suggest that the contributions of long-term memory and phonological rehearsal to memory span performance may not be simply additive. In a similar contrast, Roodenrys et al. (1993) found that 10-year-olds had very similar slopes for words and nonwords, whereas 6-year-olds showed a tendency toward a steeper slope for words than for nonwords.

Thus the nature of the long-term memory contribution to span performance is unclear. Considering how long-term memory could contribute in terms of Baddeley's model, one might expect a steeper slope in the speech rate–span relationship for stimuli that have rich long-term memory support (words) compared with stimuli that have little long-term memory support (nonwords). As discussed earlier, Baddeley (1986, 1990) has argued that information is held in a phonological store for about 2 sec before it decays. If the information is rehearsed via the articulatory control process within 2 sec, it can be refreshed and put back into the store. It is likely that some information has partially decayed from the store before it is transferred to the articulatory control process. Long-term memory could contribute by reconstructing words from partial information so that completed information would be refreshed by the articulatory control process. Consider the case in which *gorilla* is a to-be-recalled item. *Gorilla* may have partially decayed in the phonological store by the time it is to be transferred to the articulatory control process. Long-term memory could be used to supplement partial information (e.g., something akin to *gor*, *gla*, or *grl*) to reconstruct *gorilla* so that completed information is transferred to the articulatory control process. In contrast, consider the case in which a nonword such as *zegglepim* has partially decayed in the phonological store. It is unlikely that long-term memory could be used to supplement partial information to reconstruct the stimulus. Thus, the "functional" decay period may be longer for stimuli with rich long-term memory support than for stimuli with little long-term memory support. Moreover, the contribution of long-term memory would be compounded over items because there is some probability of a long-term memory contribution for each item that is transferred from the phonological store to the articulatory control process. Because more short items can be cycled through the phonological loop than long items, any boost from long-term memory should affect short items more than long items. Thus, the advantage of words over nonwords should be greater for short items than for long items. On the basis of this framework, one might expect a steeper speech rate–span slope for items with rich long-term memory support (words) than for items with little long-term memory support (nonwords). This expectation is inconsistent with the Hulme et al. (1991) Experiment 1 data (see Figure 1A).

In addition to this influence at rehearsal, long-term memory could similarly affect memory span performance by completing degraded patterns when information is retrieved from the phonological store at recall (Hulme et al., 1991; Roodenrys, Hulme, Alban, Ellis, & Brown, 1994; Schweickert, 1993). Again, because more shorter items will be available for recall, any boost from long-term memory should affect shorter items more than longer items and result in steeper slopes for items with rich long-term memory support than for items without it.

Note that this account does assume that when subjects perform a word span task, they restrict their search of long-term memory information to the items on the to-be-remembered list. Given that intrusion errors are uncommon in our experience with span tasks, this assumption seems justified. Although subjects may make the same search restriction when performing a nonword span task, it is likely of less assistance to them because the few encounters they have had with the nonwords (e.g., on previous trials) cannot compare to the years of experience people have had with the stimuli on a word span task.

The Developmental Perspective

As described above, it is presently unclear how long-term memory contributes to memory span performance. Examining this question from an adult developmental perspective may be particularly revealing. Craik and colleagues (Craik, 1984; Craik, Byrd, & Swanson, 1987) have argued that age differences in memory performance increase as environmental support that guides people through tasks decreases (also see Balota & Duchek, 1989). Consistent with this argument, some evidence suggests that older adults have relatively more difficulty than younger adults in processing stimuli that have relatively little preexisting long-term memory support. For example, older adults tend to show a greater disadvantage in processing nonwords compared with words than do younger adults (e.g., Balota & Ferraro, 1996; Madden, 1988). In the Madden study, older and younger adults made lexical decision judgments about letter strings (words or nonwords) that were presented at the end of a sentence. Both groups showed a disadvantage for processing nonwords compared with words, but this was particularly true for older adults. Collapsed across conditions, younger adults responded 112 msec (18%) slower to nonwords than to words, whereas older adults responded 238 msec (27%) slower to nonwords. The sensitivity of older adults to long-term memory contributions may reveal relatively more clearly the contribution of long-term memory to memory span performance.

In a different area of research, Balota and Duchek (1988) showed that the duration of naming single words is longer for older adults than for younger adults. This finding suggests that older adults' speech rates may be slower than younger adults' speech rates. Interestingly, there is a report by Kynette et al. (1990) that older adults do, in fact, have slower speech rates than do younger adults on a speeded speech rate task. If this finding should be replicated, then

Baddeley's model would predict smaller memory spans for older adults than for younger adults. This would fit with several studies that have investigated word span in older and younger adults (e.g., Light & Anderson, 1985; Wingfield, Stine, Lahar, & Aberdeen, 1988).

It is presently unknown whether the parameters of the speech rate–span relationship (the slope and intercept values) remain constant across different adult age groups. One possibility is that the parameters will be similar for older and younger adults. This would be consistent with the Hulme et al. (1984) report that one equation reflecting the speech rate–span relationship can capture the performance of children of different ages and young adults. An alternative possibility is that at least one of the parameters of the speech rate–span relationship will be different for older and younger adults. Such a between-groups difference has been shown between healthy children and children with spastic diplegic cerebral palsy (White, Craft, Hale, & Park, 1994) and children with Down's syndrome or severe learning disability (Hulme & Mackenzie, 1992). It is possible that such a difference in the parameters of the speech rate–span relationship could occur across older and younger adults (Balota & Duchek, 1988), particularly for nonword stimuli that are relatively difficult for older adults to process.

Summary

In order to investigate the role that long-term memory plays in memory span performance and extend our knowledge of the speech rate–span relationship to older adults, we obtained the speech rates and memory spans of older and younger adults on words and nonwords of different lengths. We expected to find length effects (shorter items articulated faster than longer items and resulting in higher spans than longer items) and lexicality effects (higher spans for words than for nonwords) in both age groups. We also expected older adults to have slower speech rates and slightly smaller memory spans than younger adults. Given that older adults have shown a particular disadvantage for processing stimuli that have relatively little long-term memory support (nonwords) compared with stimuli that have rich long-term memory support (words), older adults are a particularly revealing group to examine regarding the influence of long-term memory on memory span. In sum, there were three primary questions of interest in the present study: (1) whether the slope and intercept values from the equation that describes the speech rate–span relationship would be similar for words and nonwords or whether these values would vary across lexicality, (2) whether the data from older and younger adults could be fit by the same equation relating speech rate to span, and (3) whether any possible differences between word and nonword slopes and intercepts would be greater for older adults than for younger adults.

METHOD

Subjects

Younger adults were 24 volunteers from the Washington University campus. Their mean age was 21.92 years (*SD* = 4.28), their mean years of education was 15.33 (*SD* = 2.01), and their mean score on the last 20 items of the WAIS-R vocabulary subscale (maximum = 40) was 29.38 (*SD* = 6.65). Older adults were 24 volunteers from the Washington University Aging and Development volunteer pool. Three subjects were replaced because they had difficulty hearing the stimuli. The older adults' mean age was 67.58 (*SD* = 3.68), their mean years of education was 13.85 (*SD* = 1.96), and their mean score on the last 20 items of the WAIS-R vocabulary subscale was 30.21 (*SD* = 5.92). Younger adults had more years of education than did older adults [$F(1,46) = 6.63$, $MS_e = 3.96$, $p < .05$], but there was no difference in the vocabulary scores of the two groups ($F = 0.21$).

One older adult's speech rate data could not be determined because of a distorted session tape. When span scores were regressed onto speech rates for each subject, one older adult had a nonword slope from the speech rate–span function that was over four standard deviations above the group's mean and a nonword intercept that was over four standard deviations below the group's mean. Both subjects were excluded from further data analyses.

Materials

There were six item types that were produced by crossing the three levels of length (short, medium, and long) with the two levels of lexicality (words and nonwords). There were eight exemplars of each type that were taken primarily from Hulme et al. (1991) (see Appendix). The only changes from Hulme et al. (1991) were that we used (1) Baddeley et al.'s (1975) states category rather than the elements category, because the American version of *aluminium* only has four syllables rather than the five-syllable British pronunciation; (2) *toad* and *math* rather than *stoat* and *maths*, respectively, because the latter are relatively unfamiliar in the U.S.; (3) *page* rather than *scroll*, because the latter was phonologically similar to *school*; and (4) the nonwords *ket*, *rodfow*, and *cunderly* rather than *gug*, *maffow*, and *bepavit*, because the latter were very difficult for pilot subjects to perceive correctly.

The materials were spoken by a male and recorded by a Macintosh Classic with MacRecorder and accompanying software. Presentation of the stimuli was controlled by a modified version of STM Experimenter (Cox, Hulme, & Brown, 1992) that presented word lists created to satisfy the following constraints: (1) list lengths of three through eight were used, and there were four trials of each list length for each item type (e.g., long words); (2) eight unique items appeared across the lists for each item type; (3) no item appeared more than once on any given trial, and (4) items were used repeatedly across trials, but they were placed in different serial positions across trials. Once a master list (list of lists) satisfying these constraints was constructed, the eight items for a given type were each assigned to one of the eight possible positions in the master list. Items were then rotated through each of the seven other possible positions so that there was a total of eight orders for each item type. The eight orders were used equally across subjects in each age group. Presentation was blocked by type and the order of type presentation was counterbalanced across subjects.

Procedure

Participants were tested one at a time. A Macintosh Classic was used to present the stimuli to the subjects through headphones, and a Marantz tape recorder was used to record the session. The volume was adjusted so that the subject reported being able to hear the stimuli comfortably and the recording microphone was adjusted so that the subject reported being at a comfortable speaking level. The subject was then presented with a list of the stimuli. Each item was played through the headphones and the subject repeated it aloud.

The speech rate tasks were then administered. For the *pair task*, the subject was presented with a pair of items (e.g., *math–toad*), which he/she repeated to confirm that the items had been properly heard; then, on the presentation of a tone, the subject repeated the pair as quickly and accurately as possible until the experimenter raised her hand as a stop signal (after 10 repetitions of the pair). Subjects produced four pairs for each of the six item types; the pairs were blocked by item type. A second speech rate task was administered to explore other possible reliable speech rate measures. In this task, for each item type, the subject was asked to repeat one item once, one item 10 times (the subject counted repetitions), and one item over and over until the experimenter raised her hand as a stop signal (after 10 repetitions of the item). After receiving the instructions for an item, the subject heard the item (e.g., *radio*), repeated the item to confirm that it had been properly heard, and then on the presentation of a tone produced the repetition(s). This group of speech rate measures was also blocked by item type. For all speech rate measures, if a subject mispronounced an item, it was replayed and, if necessary, shown in written form. If a subject still misheard an item (e.g., *tappost* instead of *taffost*) the misheard version was accepted as correct. If a subject made too many or too few repetitions on any speech rate trial, the trial was repeated. Presentation was counterbalanced across subjects in terms of the following: order of the two speech rate tasks (pairs and 1/10/until stopped); order of the six item types; order of the pairs within each item type; and the items repeated once, 10 times, or until stopped within each item type.

After performing the rate tasks, subjects were then presented with the *span task*. This task was also blocked by item type and the blocks were presented in the same order as they were for the speech rate tasks. Items were presented by the modified version of STM Experimenter at a rate of one item/second. A 100-msec tone that cued recall was presented 1 sec after the onset of the last item. On each trial the subject heard items (e.g., *mumps–switch–page*) and on the presentation of the tone recalled the items in the order in which they had been presented. Each block started with a list of three items. There were four trials at each list length; this was a slight modification of the Hulme et al. (1991) procedure. If at least one of the four trials at a given length was correct, the subject was given four lists of the next length. If all four trials at a given length were incorrect, testing of that item type was stopped. Lastly, the subjects completed the vocabulary test, filled out a demographic questionnaire, and were paid and debriefed. The subjects were provided with opportunities for short breaks throughout the session.

RESULTS

Scoring

Speech rates. An Apple IIe computer with a voice-activated relay (Gerbrands, Model G1341T) was used to measure the speech time of each subject on each speech rate trial from the session tapes. The speech time was divided by the number of items repeated (e.g., 20 in the case of 10 pairs) to determine items/second. Because there were four trials of each item type on the pair task, a mean of the four speech rates was taken as the person's speech rate for that item type.

Span. Two different span measures were computed. For the cumulative span, it was assumed that people had a span of 2, and for every list they repeated correctly .25 was added to their span score for that item type. The maximum span was the largest list length that a person correctly recalled for a given item type. The same basic patterns were found for both kinds of span scores, so only the cumulative scores will be reported below.

Speech Rates

The pair rates are listed in the top of Table 1. The other speech rate measures yielded the same basic patterns, so only the pair rates will be discussed. Higher numbers indicate faster speech rates (more items/second). These data were analyzed with an age (older, younger adults) × lexicality (words, nonwords) × length (short, medium, long) mixed-factor analysis of variance (ANOVA). There are four points to note. First, older adults manifested slower speech rates than did younger adults [$F(1,44) = 12.24$, $MS_e = 1.07$, $p < .01$]. Second, speech rate decreased as item length increased [$F(2,88) = 224.15$, $MS_e = 0.11$, $p < .001$]. Third, there was an interaction between age and length [$F(2,88) = 7.13$, $MS_e = 0.11$, $p < .01$], reflecting the fact that the length effect was greater for younger than for older adults (see Hulme et al., 1984, for similar results comparing young adults and children). Fourth, there was also an interaction between lexicality and length [$F(2,88) = 20.10$, $MS_e = 0.03$, $p < .001$].

Table 1
Speech Rates in Items/Second and Cumulative Memory Spans

	Words			Nonwords		
Group	Short	Medium	Long	Short	Medium	Long
			Pair Rates			
Young						
M	2.78	1.99	1.39	2.65	2.07	1.61
SD	.60	.35	.23	.69	.46	.28
Older						
M	2.12	1.64	1.15	2.04	1.63	1.31
SD	.72	.39	.22	.66	.47	.30
			Cumulative Memory Spans			
Young						
M	4.92	4.03	3.54	3.18	2.95	2.67
SD	.75	.71	.67	.42	.47	.36
Older						
M	4.33	3.53	3.01	2.76	2.58	2.47
SD	.72	.57	.49	.51	.43	.40

The lexicality × length interaction reflects greater length effects for words (one, three, and five syllables) than for nonwords (one, two, and three syllables). Hulme et al. (1991) did not find this interaction, but it should be noted that their subjects were speaking at a relatively slow rate. Estimating from Hulme et al.'s figure, their subjects' rates ranged from only .65 to 1.45 items/sec (Figure 1A), whereas even the slower group in the present study, older adults, had rates that ranged from 1.15 to 2.12 items/ sec. It is possible that the very slow speech rates of Hulme et al.'s subjects were at floor (it would be difficult for subjects to speak much more slowly than .65 words/sec, even if the words had five syllables), thus making it difficult to detect a lexicality × length interaction. As discussed below, we believe that the difference in speech rates is partially due to the present subjects' having more practice with the stimuli, and the disproportionate benefit of practice on novel stimuli. However, before discussing this issue in detail, we will present the span data and data regarding the speech rate–span relationship.

Span

The cumulative memory spans are listed in the bottom of Table 1. These data were analyzed with an age (older, younger adults) × lexicality (words, nonwords) × length (short, medium, long) mixed-factor ANOVA. There are four points to note. First, older adults had smaller spans than younger adults [$F(1,44) = 11.15$, $MS_e = 1.16$, $p < .01$]. Second, spans were greater for words than for nonwords [$F(1,44) = 352.21$, $MS_e = 0.25$, $p < .001$]. Third, spans decreased as item length increased [$F(2,88) = 162.22$, $MS_e = 0.11$, $p < .001$]. Fourth, as in the rate data, there was a lexicality × length interaction [$F(2,88) = 42.87$, $MS_e = 0.12$, $p < .001$], reflecting a greater length effect for words than for nonwords. Hulme et al. (1991) did not find a lexicality × length interaction in their span data. This will be addressed further in the Discussion.

The most important aspect of the span data is the greater span for words than for nonwords. Hulme et al. (1991, Experiment 1) showed that when speech rates did not differ for words and nonwords, words still resulted in higher memory span. The present data extend their finding to the case in which speech rates for words tended to be *slower* than speech rates for nonwords, particularly for long words (five syllables) and nonwords (three syllables), yet spans for the words were *higher* than spans for the nonwords. Thus, consistent with Hulme et al.'s conclusion, in the present data speech rate alone cannot account for memory span performance.

Speech Rate–Span Relationship

Figure 1B shows the speech rate–span relationships for words and nonwords for younger (filled symbols) and older (open symbols) adults. For the word and nonword means for both age groups, long items are the leftmost points, medium items are the middle points, and short items are the rightmost points. There are four points to note: First, speech rates and spans increase as item length decreases, reconfirming the length effects reported by Baddeley et al. (1975). Second, the fit of the regression lines for the words and the nonwords is very good (r^2 of .97 for words and .94 for nonwords), supporting previous descriptions of the strong relationship between speech rate and memory span (e.g., Baddeley, 1986, 1990; Schweickert & Boruff, 1986). Third, the separate regression lines for words and nonwords suggest that the simple Baddeley model ($s = rt + c$) needs to be modified if it is to accurately reflect the processes that underlie memory span performance. Long-term memory contributions, as well as speech rate contributions, must be considered. Fourth, in contrast to the findings of Hulme et al. (1991), the slope of the speech rate–span relationship for words is greater than the slope of the speech rate–span relationship for nonwords.

The relationship between speech rate and memory span was further explored by using individual scores. Spans were regressed onto speech rates for each subject, resulting in slopes and intercepts for words and nonwords for each subject. These slope and intercept scores were then analyzed with separate age (older, younger adults) × lexicality (words, nonwords) mixed-factor ANOVAs. The slope analysis yielded a significant main effect of lexicality [$F(1,44) = 19.40$, $MS_e = 0.98$, $p < .001$], and a marginal age × lexicality interaction [$F(1,44) = 3.35$, $MS_e = 0.98$, $p < .08$]. The intercept analysis yielded a marginal age × lexicality interaction [$F(1,44) = 3.40$, $MS_e = 1.90$, $p < .08$]. Although it was predicted, the age × lexicality interaction for the slopes only approached significance. This was largely because of a subset of older adults who were at floor in span scores. When subjects who showed floor performance were removed from the analysis (1 younger and 2 older adults had 0 trials correct on the medium and long nonwords), this interaction was significant [$F(1,41) = 5.08$, $MS_e = 0.93$, $p < .05$].

Figure 2 shows the speech rate–span relationship separately for younger (panel A) and older adults (panel B). When individual subject slopes and intercepts were sep-

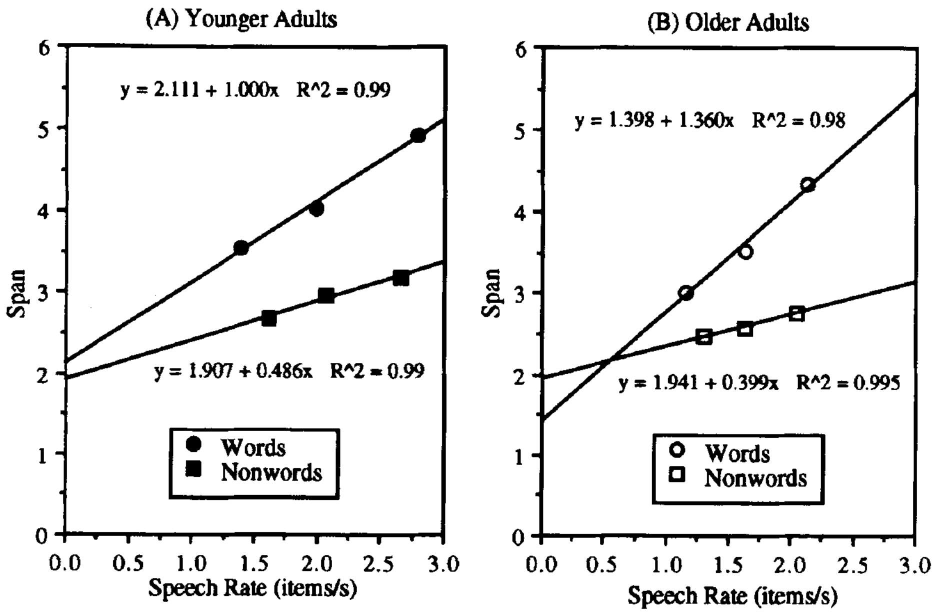

Figure 2. (A) Regression of cumulative spans onto speech rates for younger adults. (B) Regression of cumulative spans onto speech rates for older adults. For both panels, on words and nonwords the leftmost points are long items, the middle points are medium items, and the rightmost points are short items.

arately analyzed, younger adults showed greater slopes for words than for nonwords [$F(1,23) = 7.14$, $MS_e = 0.48$, $p < .05$] and similar word and nonword intercepts [$F(1,23) = 1.01$, $MS_e = 1.04$, $p > .10$]. Similarly, older adults showed greater slopes for words than for nonwords [$F(1,21) = 11.91$, $MS_e = 1.53$, $p < .01$] and similar word and nonword intercepts [$F(1,21) = 2.27$, $MS_e = 2.84$, $p > .10$].

The age × lexicality interaction reported in the overall analysis of the slopes reflects the greater difference between word and nonword slopes for the older adults (panel B) than for the younger adults (panel A). Interestingly, there is little difference across groups in the nonword function. As shown in Figure 2, the interaction is primarily driven by the word slope's being steeper for the older than for the younger adults. The age × lexicality interaction is consistent with the prediction discussed in the introduction that older adults would show a larger influence of long-term memory structure.

In an attempt to rule out floor effects, particularly for the nonwords, as an explanation for the difference in slopes for words and nonwords, a median split was done separately for younger and older adults based on the mean of the subjects' six span scores. The top half of the younger adults had spans that ranged from 2.25 (long nonwords) to 6.50 (short words), and the top half of the older adults had spans that ranged from 2.00 (long nonwords) to 6.25 (short words). Importantly, the mean span for the most difficult item type, long nonwords, was 2.79 for the top half of the younger adults and 2.57 for the top half of the older adults, both of which are at least as large as the long nonword spans of the Hulme et al. (1991, Experiment 1) subjects (approximately 2.25; see Figure 1A). The mean spans for short, medium, and long words and short and medium nonwords were 5.46, 4.48, 3.96, 3.46, and 3.17, respectively, for younger adults and 4.73, 3.91, 3.27, 3.16, and 2.77, respectively, for older adults. The ANOVAs on speech rates, spans, slopes, and intercepts described above were repeated on the top half of the subjects from the median splits and resulted in the same patterns reported in the overall analyses. Most importantly, significant lexicality × length interactions in speech rates [$F(2,42) = 11.26$] and spans [$F(2,42) = 13.69$] were found. Slopes were greater for words than for nonwords [$F(1,21) = 5.75$] and there were no differences in intercepts [$F(1,21) = 0.17$]. The data were fit well by regression lines (r^2s of .93 for words and .94 for nonwords). Thus, the results of these analyses suggest that the findings reported above are stable and not simply due to floor effects in the data set.

DISCUSSION

As in the data reported by Hulme et al. (1991), in the present data words were recalled better than nonwords to an extent that could not be attributed to simply differences in speech rate. However, contrary to the findings of Hulme et al. (1991, see Figure 1A), the present data (see Figures 1B and 2 and the accompanying analyses) suggest that the slope of the speech rate–span relationship varied across lexicality. It appears that the boost in span performance from long-term memory representation, as reflected by the lexicality effect, is greater for shorter than for longer items, resulting in steeper slopes for words than for nonwords. This is consistent with the description in the introduction regarding how long-term memory could contribute to span performance in terms of Baddeley's (1986, 1990) model. Briefly, long-term memory could help in reconstructing partially decayed information. Because more short than long items can be cycled through the phonological loop, short items provide more opportunity for long-term memory contribution than do long items. The present data suggest that the relationship between the contributions of long-term memory and rehearsal rate to memory span performance is not simply additive.

Hulme et al. (1991) reported similar speech rates for words and nonwords. In the present study, speech rates differed for words and nonwords. However, what is most critical to our understanding of the contribution of long-term memory to memory span performance is not equal speech rates across lexicality; it is the relationship between speech rate and span that is depicted by the regression lines. In the present data, the regression function for speech rates and spans fit the data very well (r^2 of .97 for words and .94 for nonwords in Figure 1B and r^2s of .98 and .99 in Figure 2). There are points along the word function that index the same speech rates as those found for the nonwords. Importantly, even when these points are compared with the nonword points, there are greater lexicality effects for short than for longer items. This increase in the lexicality effect as item length decreases clearly suggests that the contribution of long-term memory varies according to how quickly items can be cycled through the phonological loop.

Why should Hulme et al.'s (1991) data indicate an additive contribution of long-term memory to memory span performance while our data, based on virtually the same stimuli as those used by Hulme et al., indicate a more complicated contribution? As noted earlier, one important difference between the studies is that our subjects were more practiced on nonwords than Hulme et al.'s subjects were. Their subjects repeated pairs of items five times before doing the span task. Our subjects repeated pairs of items 10 times, and they also did several other speech rate tasks with a subset of the items. The increased practice that our subjects had with the items may have enhanced their speech production programs for the more difficult items—namely, the long nonwords. Such a pattern is consistent with the familiarity × repetition interaction in which repetition effects are larger for less familiar low-frequency words than for high-frequency words (cf. Scarborough, Cortese, & Scarborough, 1977). Because one would expect the practice effect to be larger for longer unfamiliar items (nonwords), the spans for longer unfamiliar items would have been particularly increased, resulting in a relatively lower slope for the nonwords in the present data. For our purposes, we believe that it is desirable to have the subjects well practiced on the materials so that the patterns in the data reveal effects of our variables of interest rather than any possible difficulties in the speech production programs for difficult items such as longer nonwords.

Note that the present data cannot be explained in terms of differences in word frequency across length. The median frequencies (roughly, frequency per million words) for the short, medium, and long words were 16, 13, and 6, respectively, excluding *mumps*, *gorilla*, and *hippopotamus*, which were not reported in Kučera and Francis (1967). There are several reasons why the slight differences in word frequency cannot explain our results. First, it is important to note that the rate and span differences were at least as large when comparing short and medium words which were virtually identical in terms of median frequency as when comparing medium and long words which had a slightly larger difference in frequency. Most importantly, the median frequencies are similar in our stimuli and in Hulme et al.'s (1991) stimuli. Their median frequencies for short, medium, and long words were 30, 13, and 6. In fact, if small differences in frequency rather than word length were driving the slopes, then, on the basis of the fact that Hulme et al. had a slightly larger range of frequencies, one would expect that the Hulme et al. data would show more exaggerated differences in slopes than would our data, which is not the case. Thus, we believe that the effects we report cannot be attributed to frequency effects.

Investigations of the contribution of long-term memory to memory span performance have now provided five data sets for comparing performance on words and nonwords. Two of the data sets (Hulme et al., 1991, Experiment 1, $n = 12$; the 10-year-olds in Roodenrys et al., 1993, $n = 12$) show similar slopes for words and nonwords, whereas the other three data sets (the present younger adults, $n = 24$; the present older adults, $n = 22$; the 6-year-olds in Roodenrys et al., 1993, $n = 12$) show steeper slopes for words than for nonwords. It is possible that certain conditions can lead to similar slopes for words and nonwords (e.g., when subjects are not instructed to speak as quickly and accurately as possible as in Hulme et al., 1991, and when relatively fast speakers are compared on words and nonwords of equal syllable length as in the 10-year-olds in Roodenrys et al., 1993). However, we believe that in the absence of such special conditions, long-term memory contributions affect the slope of the speech rate–span relationship. This conclusion is bolstered by the fact that the present data have the most power to reveal a difference in slopes for words and nonwords, on the basis of the sample sizes listed above, and they indicate that the contribution of long-term memory to span performance is not simply additive.

In the present data, both older and younger adults showed steeper slopes in the speech rate–span relationship for words than for nonwords (see Figures 1B and 2). When subjects who were at floor were removed from the slope analysis, there was the predicted age × lexicality interaction. This pattern of data is consistent with previous findings that older adults show a particular advantage in processing words compared with nonwords—that is, items with rich long-term memory support compared with items with relatively little long-term memory support (e.g., Balota & Ferraro, 1996; Madden, 1988). However, this finding must be interpreted with caution because the effect was marginal in the overall analysis. It will be important to replicate this finding with other materials, perhaps with nonwords that more closely approximate English words and other materials that vary with respect to the degree of long-term memory support (e.g., varying in terms of concreteness or frequency).

Summary

Several aspects of the present data support Baddeley's (1986, 1990) model of a phonological rehearsal process underlying memory span performance, whereas other aspects of the data suggest that the model needs modification. Consistent with the Baddeley model were the findings that differences in speech rate, and thus presumably differences in rehearsal rate, could account for the age and length effects on memory span. Inconsistent with the Baddeley model was the finding that speech rates alone could not account for the lexicality effects. The latter effects confirm previous suggestions (Besner & Davelaar, 1982; Bourassa & Besner, 1994; Brooks & Watkins, 1990; Craik, 1971; Hulme et al., 1991; Roodenrys et al., 1993; Roodenrys et al., 1994; Watkins, 1977) that more than one process underlies memory span performance, and, more specifically, that long-term memory contributes to span performance. In the present experiment, the slope parameter of the speech rate–span relationship was greater for words than for nonwords. These data suggest that the magnitude of the long-term memory contribution to memory span performance depends on how quickly information can be cycled through the phonological loop. Long-term memory has more of an effect on items that can be rehearsed relatively quickly (short items) than on items that are rehearsed relatively slowly (long items).

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APPENDIX

Short Words (1 Syllable)	Medium Words (3 Syllables)	Long Words (5 Syllables)
toad	gorilla	hippopota-
mus		
mumps	leprosy	tuberculosis
school	nursery	university
Greece	Mexico	Yugoslavia
switch	radio	refrigerator
math	botany	physiology
page	bulletin	periodical
Maine	Wyoming	Louisiana
Short Nonwords (1 Syllable)	**Medium Nonwords (2 Syllables)**	**Long Nonwords (3 Syllables)**
fot	rodfow	cunderly
zog	taffost	jodazum
mab	crepog	arellum
bim	teggid	tushebon
dof	giffol	zegglepim
ket	ballem	gossikos
pid	grelup	muttasek
sep	swijit	monoisip

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