

## Research Article

## THERE ARE TWO WORD-LENGTH EFFECTS IN VERBAL SHORT-TERM MEMORY: Opposed Effects of Duration and Complexity

Nelson Cowan,<sup>1</sup> Noelle L. Wood,<sup>1</sup> Lara D. Nugent,<sup>1</sup> and Michel Treisman<sup>2</sup>

<sup>1</sup>University of Missouri and <sup>2</sup>University of Oxford, England

**Abstract**—In the word-length effect (WLE), lists of shorter words are better recalled than lists of longer words. This effect is fundamental to decay-based theories of verbal short-term memory, such as the phonological loop theory (Baddeley, 1986). The WLE has been attributed to the time taken to articulate words, not their structure, a critical point in the debate between decay and interference theories. However, word duration and complexity have previously been confounded. In this article, we show that the traditional WLE comprises two opposed effects: an advantage for words spoken more quickly (short words in terms of duration) and an advantage for words with more elements (long words in terms of complexity). We also report two interactions: a disadvantage for a midlist change in duration and an advantage for a midlist change in complexity. These results contradict simple decay-based theories and establish the importance of interference in short-term memory. We discuss whether decay is also required.

Dual-storage theories of memory combine a short-term store (STS) of low capacity with a long-term store of greater capacity (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965). Recently, such models have been questioned. One challenge comes from the *through-list distractor* (TLD) procedure, in which a distracting task is performed for 10 to 20 s before each list item and after the last item. Such delays should ensure that any short-term representation has decayed away by the time of recall. Yet the TLD procedure produces a recency effect, which previously had been attributed to the contribution of decay in the STS (Bjork & Whitten, 1974; Crowder, 1993; Gardiner & Gregg, 1979; Glenberg, 1984; Greene, 1986). Furthermore, recency effects for the short-term retention of item and order information extend over different ranges and have different slopes, which presents another problem for simple decay theories (White & Treisman, in press).

Are serial position effects evidence for an STS in which decay occurs (with decay defined as degradation of a memory representation solely through the passage of time), or are they manifestations of interference in memory (Wickelgren, 1975a, 1975b)? We offer some evidence on this question, focusing on the *word-length effect* (WLE), or better recall of lists composed of shorter words than longer words, first obtained by Baddeley, Thomson, and Buchanan (1975). It is believed that the WLE is determined by the time taken to articulate the words, rather than the number of syllables or phonemes, because memory span is poorer on lists including words like *Friday* and *zygote* than on lists including words like *bishop* and *wicket* (Baddeley et al., 1975). Although they are matched on syllable number, phoneme number, and frequency, the latter lists are spoken more quickly. Baddeley

(1986) interpreted the WLE in terms of his phonological loop theory, which assumes that word representations decay in the STS except when they are actively maintained or refreshed in a phonological loop. An item cannot be refreshed after its representation has decayed totally, so the number of words that can be included in the loop depends on the word length, which affects the number of items that can be rehearsed before they decay. Thus, the WLE has been viewed as supporting the concept of STS decay.

Three questions arise and are pursued in this report. First, is the WLE restricted to the usual immediate-presentation (IP) procedure in which words follow one another immediately, as STS decay theories predict, or does a similar effect occur in the TLD procedure? Second, does the WLE depend solely on the stimulus duration, or does the structural complexity of the words play a role? Third, can the results be explained solely by a decay theory, or by an interference theory, or is some combination of interference and decay required?

Our approach stems from two prior studies. First, using an IP procedure, Cowan et al. (1992) examined the WLE by varying the lengths of words in the first and second halves of the list independently, and also varying the direction of recall (forward or backward, cued after presentation of the list).

For convenience, we refer to the words in the half-list presented first as the P1 words (Positions 1, 2, and 3 in a six-item list) and those in the half-list presented second as the P2 words (Positions 4, 5, and 6). Similarly, R1 and R2 represent the half-lists recalled first and second, respectively. With forward recall, R1 is P1 and R2 is P2. With backward recall, R1 is P2 (i.e., Positions 6, 5, 4, recalled in that order) and R2 is P1.

Cowan et al. (1992) found that regardless of whether recall was forward or backward, the level of recall throughout the list was affected by the lengths of R1 words but not by the lengths of R2 words. This result suggested that it was the process of overtly recalling R1 words that influenced recall of R2 words, which is not consistent with Baddeley's (1986) assumption that the memory loss occurs specifically during presentation. However, Cowan et al. still retained the STS decay hypothesis, proposing that R2 words decay in the time taken up recalling R1 words.

Second, Cowan, Wood, and Borne (1994) compared backward recall in an IP task and a TLD procedure, using one- and three-syllable words. (Backward recall ensures that any effects of R1 words cannot be attributed to their being available for rehearsal longer than R2 words, as R2 words were presented first.) For the IP procedure, the advantage of having short words in R1 was replicated. However, for the TLD procedure, there was an advantage for long rather than short words, both in R1 and in R2. Cowan, Wood, and Borne proposed that the short-word advantage could occur only while an STS representation had not yet fully decayed, as in the IP procedure.

In this article, we report first a replication we conducted to resolve an ambiguity in the latter study. On each TLD trial of that study,

Address correspondence to Nelson Cowan, Department of Psychology, University of Missouri, 210 McAlester Hall, Columbia, MO 65211, e-mail: pycowan@showme.missouri.edu, or to Michel Treisman, Department of Experimental Psychology, South Parks Rd., Oxford OX1 3UD, England.

subjects read 30 digits aloud initially and following each word of the list. Digits are more similar to one-syllable words than to three-syllable words, eight of nine being monosyllabic. Materials similar to the items to be recalled can produce more interference than dissimilar ones (Deutsch, 1975; Massaro, 1970; Waugh & Norman, 1965). If the distractors produced interference, there could have been more interference with one-syllable list words than with multisyllabic words, obscuring any short-word advantage in the TLD procedure. To eliminate this possibility, we investigated whether the long-word advantage in TLD recall remained when multisyllabic distractors were used instead of digits. This study cleared the way to examine, in a second experiment, whether word duration and structural complexity both contribute to the WLE and how the results can be explained.

## EXPERIMENT 1

### Method

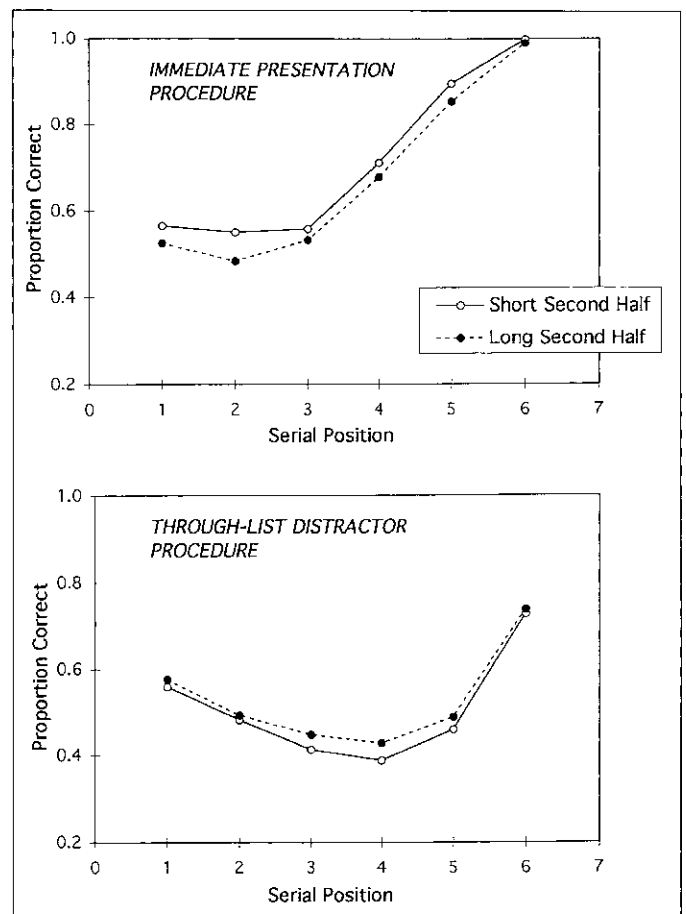
The participants were 60 undergraduate psychology students (40 women, 20 men) who received course credit. The procedures were identical with those of Cowan, Wood, and Borne (1994) except for the distractors in the TLD procedure. The distractors were nine printing symbols that appeared singly in random order for 15-s periods initially and after each list item presented. They were pronounced as three- or four-syllable words, as follows: exclamation [!], percentage [%], ampersand [&], asterisk [\*], parentheses [( )], semicolon [;], apostrophe ['], period [.] and quotation [“ ”]. To allow sufficient time for the subjects to read the distractors comfortably, we presented them at a 1.5-s onset-to-onset interval, three times slower than the rate for the monosyllables used previously. As before, all items were read aloud by the subjects, recall was backward, and the order of IP and TLD conditions was counterbalanced across subjects.

### Results and Discussion

The IP results, shown at the top of Figure 1, replicated those of Cowan, Wood, and Borne (1994) so closely that they are practically indistinguishable. The main effect of R1 (P2) word length was again significant,  $F(1, 58) = 8.12, p < .01$ . Overall performance was 71% with R1 short and 68% with R1 long. As in Cowan et al. (1992) and Cowan, Wood, and Borne (1994), there was no significant main effect of R2 (i.e., P1) word length.

In the TLD procedure, Cowan, Wood, and Borne (1994) found advantages for lists with long first and second halves. In the present experiment, the long-word advantage was replicated for R2 (P1),  $F(1, 58) = 7.69, p < .01$ . Performance was 49% for R2 short and 54% for R2 long. The advantage for long words in R1 (P2) was not significant in this experiment, but the means did favor long words in R1 (see Fig. 1, bottom). These findings eliminate the possibility that the long-word advantage previously found with TLD was caused by the similarity in word length between short target words and distractors. They do not eliminate the possibility that susceptibility to interference is greater for similar stimuli, but any effect of word-length similarity is not sufficient to explain the difference between the IP and TLD results.

Experiment 1 confirmed that the WLEs in the IP and TLD procedures are opposite in direction. We next examine the ordinary WLE in the IP procedure more analytically, to distinguish the effects of two variables that have remained confounded until now.



**Fig. 1.** Results for Experiment 1 as a function of input serial position, for backward recall in the immediate-presentation procedure (top panel) and the through-list distractor procedure (bottom panel). Curves are shown for trials composed of either short words (short-duration monosyllables) or long words (long-duration trisyllables) in the second half-list presented (which was recalled first), averaged over trials with short and long words in the first half-list presented (which was recalled second).

## EXPERIMENT 2

Cowan, Wood, and Borne (1994) interpreted their IP results as based on STS decay, and that result was replicated in Experiment 1. However, the characteristics of decay cannot explain the long-word advantage that occurred in the TLD procedure. An interference theory is an alternative that needs to be considered. Could all of the results (IP and TLD) be accounted for with an interference theory? To examine this question, more information about the ordinary WLE is required.

The assumption that the WLE depends on duration has been important for the STS decay concept, but the evidence for this assumption is questionable. Previous experimenters have obtained duration effects while controlling for word complexity, but the controls may have been insufficient: The duration effects were obtained with the number of phonemes and syllables equated across durations, but the effects of the number of stresses in a word have remained uncontrolled. The number of stresses is of considerable importance in

speech production (Sternberg, Monsell, Knoll, & Wright, 1978; Sternberg, Wright, Knoll, & Monsell, 1980). Though a quickly spoken word such as "wicket" may be matched in syllables and phonemes to a slower word such as "Friday," the former has one stressed syllable, and the latter has two. In this respect, word complexity has been confounded with pronunciation duration in previous work (Baddeley et al., 1975; Cowan et al., 1992). In our second experiment, we examined the WLE with a design that truly separated duration effects from complexity effects.

To unconfound word duration and word complexity, we used two durations, crossed with two levels of complexity. (We make no attempt here to distinguish between the number of syllables and the number of stresses in defining word complexity; that is left for future work.) The vocabularies were monosyllabic words with one stress and disyllabic words with two stresses. In contrast with all previous studies, the same words were used for the short- and long-duration word sets, and duration was manipulated by training participants to pronounce words quickly or slowly to cue, during both visual presentation and spoken recall.

If we found that duration produced a WLE but variation in complexity had no effect, this would strengthen the "decay in STS" theory. If complexity had an effect but duration had none, this would speak to the action of interference alone. If both duration and complexity effects were found, this could be explained either by a fuller interference theory or by a combination of interference and decay, as we discuss later.

## Method

Twenty undergraduates (15 females, 5 males) from the University of Missouri participated for course credit. The monosyllabic words were *dome*, *gate*, *lamp*, *nest*, *rice*, and *tank*. The disyllabic, doubly stressed words were *bedroom*, *cocktail*, *football*, *hardware*, *platform*, and *sunlight*. These sets are approximately matched in frequency (Kucera & Francis, 1967) and imageability (Quinlan, 1992).

An IP procedure with backward recall was used, but with pronunciation duration controlled. A pronunciation duration signal preceded each word during presentation and recall. This signal was a row of stars that increased in number, thus growing longer, over 300 ms or 600 ms, indicating the short or long target duration that was to be matched by the subject's pronunciation. A given word was preceded by the same signal in presentation and recall within a particular list, although the same word could be treated differently in different lists. No word was used more than once in a list.

After initial training in controlling pronunciation duration, five trial blocks were run, with each of 16 conditions represented once per block in a new random order. The number of syllables and pronunciation duration were determined separately for the first three and last three words in each six-word list. If the first and second halves of a list are represented sequentially (i.e., in P1-P2 order), there were four trial types in which both halves had the same syllable number and duration (short monosyllables–short monosyllables, long monosyllables–long monosyllables, short disyllables–short disyllables, and long disyllables–long disyllables); four in which the number of syllables but not the duration signal changed midlist (short monosyllables–short disyllables, short disyllables–short monosyllables, long monosyllables–long disyllables, and long disyllables–long monosyllables); and four in which only the pronunciation duration changed midlist (short

monosyllables–long monosyllables, long monosyllables–short monosyllables, short disyllables–long disyllables, and long disyllables–short disyllables). Four types of filler trials were included, with either the number of syllables (one or two) or the duration (short or long) randomly varying across the list (monosyllables of short or long durations, disyllables of short or long durations, short words of one or two syllables, and long words of one or two syllables).

## Results and Discussion

Speaking durations were measured during presentation and recall for a randomly selected trial from each condition for every subject, using a waveform editor. These data showed that the manipulation successfully produced different pronunciation durations (see Table 1).

Two analyses of the data were conducted: one for conditions in which duration was constant throughout the list, allowing a detailed examination of syllable-number effects, and one in which syllable number was constant throughout the list, allowing a detailed examination of duration effects. The results reported here refer to either analysis, as appropriate.

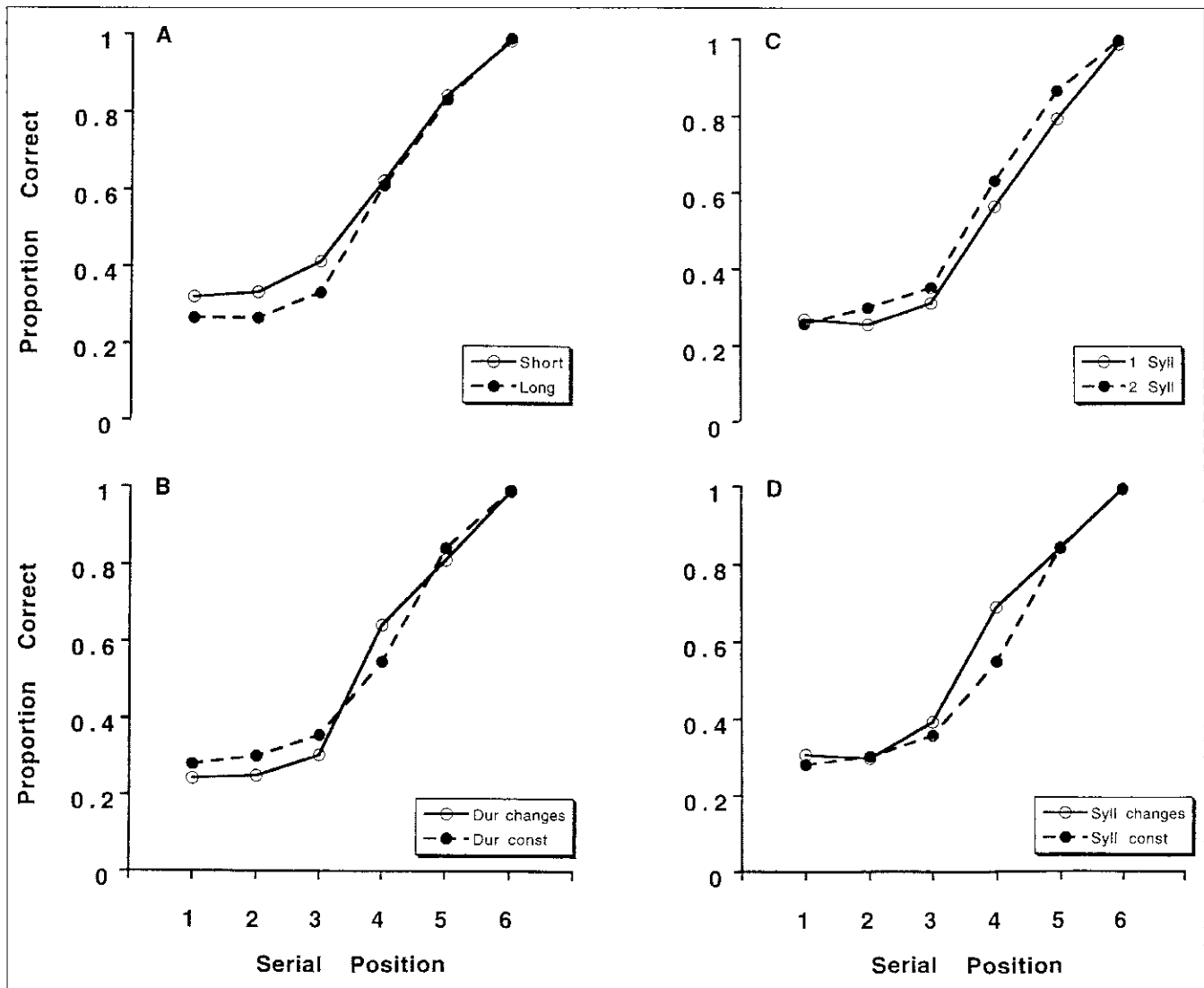
Figure 2 shows that when we unconfounded word duration and complexity, the traditional WLE broke down into two opposed types of effect, one a function of duration, the other of complexity.

The effects of duration are shown on the left. Figure 2a shows the proportion correct at each serial position when all syllables were either short or long in duration, averaged over counterbalanced syllable numbers. There is a significant main effect favoring short-duration words,  $F(1, 19) = 8.56, p < .01$ . The effect was greatest for the words recalled last, producing an interaction of Pronunciation Duration  $\times$  Serial Position,  $F(5, 95) = 2.51, p < .05$ . This finding supports the view that the process of recalling words affects the subsequent recall of other words. We refer to this type of WLE as the *word-duration effect*.

When word durations in R1 and R2 were manipulated independently, we did not obtain a main effect of R1 duration (unlike Cowan et al., 1992; Cowan, Wood, & Borne, 1994). Figure 2b shows what dominant effect we found instead. It compares series in which all words had the same duration throughout the list (either all short or all long) with series in which the duration changed (either R1 short and R2 long or R1 long and R2 short). In all cases, syllable number was constant throughout the list. These data show a disadvantage of changing duration for recall of the R2 words. This disadvantage was found whether the change was from R1 long to R2 short or vice versa. The

**Table 1.** Estimates of mean spoken word durations (in milliseconds) produced by participants in Experiment 1 under "short" and "long" pronunciation instructions

Word type	Instructed duration	
	Short	Long
	Input phase of trial	
Monosyllabic	435	801
Disyllabic	531	956
	Output phase of trial	
Monosyllabic	445	809
Disyllabic	552	985



**Fig. 2.** Average proportion correct at each input serial position in Experiment 2. Results are shown for trials in which (a) the words were all short duration or long duration, with syllable number constant or counterbalanced; (b) word duration (Dur) changed or was constant, with syllable number always constant; (c) the words were all monosyllables or all disyllables, with duration constant or counterbalanced; and (d) syllable (Syll) number changed or was constant, with duration always constant.

effect produced a significant three-way interaction of R1 Duration  $\times$  R2 Duration  $\times$  Serial Position,  $F(5, 95) = 4.75, p < .001$ . This finding can be explained by a disruptive effect of changing output pace midlist. Subjects questioned afterward volunteered that this change seemed effortful and distracting.

The panels on the right of Figure 2 examine effects of complexity. Figure 2c shows an overall advantage for disyllables,  $F(1, 19) = 5.37, p < .05$ . This advantage could occur because words with more elements contain more cues that may survive interference. We refer to this WLE, which is in the reversed direction from the traditional effect, as the *word-complexity effect*. (Complexity may include contributions of syllable number per se, number of stresses, ease of articulation, and vowel type, which cannot be clearly distinguished from one another in this article but are discussed by Caplan, Rochon, & Waters, 1992; Caplan & Waters, 1994.)

Figure 2d compares series in which syllable number was constant

throughout the list (all monosyllables or all disyllables) with series in which there was a change in syllable number midlist (in either direction—from one to two, or from two to one). There was an advantage for a change in syllable number, regardless of the direction. The corresponding interaction, R1 Syllables  $\times$  R2 Syllables  $\times$  Serial Position, was significant,  $F(5, 95) = 5.73, p < .001$ .

Note that in Figures 2b and 2d, the dashed-line curves are identical, representing data with both duration and syllable number constant. Using this as a common reference, one can see that although a duration change was a disadvantage (Fig. 2b), a change in syllable number was an advantage (Fig. 2d). The syllabic change allows the list to be grouped into two sublists of three items each, and there are potential benefits of such grouping (Frick, 1989). One advantage is in serial position information. A subject recalling a homogeneous list has five possible ways to mislocate any word, but if the list comprises half-lists of three monosyllables and three disyllables, the complexity

of each word indicates the half-list in which it is located. This line of reasoning suggests that the advantage should be greatest at the boundary between the groups, and it is.

Both duration and complexity of the words caused only small changes in the level of performance. A greater influence on recall was a word's serial position. Previous work (Cowan et al., 1992) suggests that the position of the word in the response protocol, not in the stimulus list, is most important in determining the level of recall. This influence of response position supports the occurrence of massive interference between items during recall.

### GENERAL DISCUSSION

How far do these findings go in helping to resolve the theoretical issues? We consider the two approaches in turn. To clarify the implications of an interference theory, it can be expressed in terms of three assumptions:

1. Stored information may be degraded by interference from ongoing processing or activity, at any stage of acquisition or retrieval. Thus, uttering a word or phonologically processing auditory input may interfere with the retention of other words recently stored in memory.
2. As the duration of a spoken stimulus increases, the interference it produces increases. This increase is a function of the total auditory input to the phonological system, which is greater for words that take longer to utter.
3. An item defined by more information is more resistant to interference than is a less complex stimulus. As information is lost, the more complex item retains sufficient information to cue the correct response for a longer period.

One of us (M.T.) maintains that interference can account for all the present findings. The traditional WLE in the IP procedure of Experiment 1 is explained by greater interference on R2 words from longer R1 words than from shorter R1 words. The long-word advantage in the TLD procedure is explained by the assumption that more complex material is more resistant to interference. With so many interfering stimuli following each word in this procedure, the phonological representation is more severely degraded, and the amount of residual information remaining becomes critical. Residual information is assumed to be greater for words with more phonetic elements, which serve as clues to the appropriate response (cf. Brown & Hulme, 1995).

The failure of multisyllabic distractors to neutralize the long-word advantage indicates that at least when defined in terms of word length, similarity is not important in determining interference. Three monosyllables may have much the same effect as one trisyllable, perhaps because the total auditory input they generate is similar.

In Experiment 2, we found an advantage for disyllables over monosyllables, the word-complexity effect (Fig. 2c), which is explained by the assumption that more complex words are more resistant to interference. This effect is distributed over the whole list; it is not restricted to R2 only, as one would expect if the effect arose during the output of R1 words. This finding suggests the effect may arise during acquisition, or from the way storage is implemented during acquisition. (For an account of how storage implementation and retrieval procedures may affect retrieval, see Treisman & Doctor, 1987.)

Comparing lists homogeneous in word duration, and with word complexity controlled, we found an advantage for short durations (Fig. 2a) that is seen particularly in the words recalled last, as we would expect if the effect is produced by interference from R1 words. On the interference account, this advantage is explained by the dependence of the interference produced on the total auditory input, which in turn depends on the duration over which a word is pronounced.

The assumption that interference builds up as a function of processing effort cumulated over time would explain the tendency for memory span to be related to the number of items the subject can pronounce in 2 s (Baddeley et al., 1975).

Finally, the two interactions found in Experiment 2 can be explained by further types of interference, the distracting or disruptive effect on performance arising from a change of pace (Fig. 2b) and the greater vulnerability of serial position information in lists that are homogeneous rather than heterogeneous in syllable number and therefore have less internal structure (Fig. 2d).

According to this view, interference theory accounts parsimoniously for all the present observations, making it unnecessary to posit decay. (Another interference theory for the WLE has been proposed by Neath & Nairne, 1995, but it cannot account for all the present findings.)

Some of us (N.C., N.L.W.) accept that interference is required to account for the word-complexity effect, but argue that memory decay may account for the duration effect. This account assumes that rehearsal or memory reactivation during recall often counteracts decay. The memory loss presumably is greater with longer duration R1 words, not because of the interference produced by their auditory contents, but because the utterance of these words prevents reactivation for longer. Though decay and rehearsal assumptions may be less parsimonious than interference theory alone in explaining the present results in isolation, many authors have reported types of memory loss that suggest decay rather than interference (Cowan, Lichty, & Grove, 1990; Keller, Cowan, & Saults, 1995; Lü, Williamson, & Kaufman, 1992; Reitman, 1974; Sams, Hari, Rif, & Knuutila, 1993; Watkins, Watkins, Craik, & Mazuryk, 1973).

Cowan, Wood, and Borne (1994) found that whether recall was paced at 2 s per item or self-paced, similar results were obtained. That is why it may be necessary to postulate that decay occurs only during the utterance of responses in recall, not during silent intervals. The theory would assume that while the R1 words are being pronounced, rehearsal is prevented, allowing the representations of R2 words to decay.

Another motivation for including decay and rehearsal in accounts of serial recall is to explain why a person's memory span for a particular type of item is about equal to the maximal number of those items that the person can pronounce (and presumably, could rehearse) in 2 s (Baddeley et al., 1975). Baddeley et al. proposed that the 2-s period was the duration of a decaying trace. The 2-s constant probably cannot be attributed to output interference during recall, given that individual memory spans in childhood are related to the durations of the silent periods, not the words, in the actual, self-paced recall responses for lists of a fixed, subspan length (Cowan, Keller, et al., 1994).

We have found that word complexity and duration produce opposite effects, which are confounded in the traditional WLE. What determines the direction of the observed WLE when these variables act

together? It is likely that this depends on the relative sizes of the differences in complexity and duration between the experimental conditions. For example, *zygote* and *wicket* may differ more in duration than they do in complexity. (*Wicket* has one less stress.) This situation would favor a net duration effect, as Baddeley et al. (1975) obtained. However, if the contribution of effects arising during performance in recall is reduced, complexity effects arising from listwide interference in acquisition may become evident. Two studies (Caplan et al., 1992; Caplan & Waters, 1994) using long and short words matched in syllable and phoneme numbers but with the former containing tense vowels and taking longer to pronounce, and requiring subjects to respond not verbally but by pointing at visual representations of the stimuli, yielded advantages for long words.

We have unconfounded the effects of temporal duration and morphological complexity and have shown that both are important in immediate, spoken, serial recall. The results can be explained by interference alone, though we have also considered a possible contribution of decay. In either analysis, the WLE can no longer be considered a satisfactory basis for positing concepts based on decay but not interference, such as the phonological loop (Baddeley, 1986).

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