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Memory-search and rehearsal processes and the word length effect in immediate recall: A synthesis in reply to Service

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We would like to begin by offering a new theoretical account of the duration-based part of the word length effect, inspired partly by the recent literature and partly by Service's comments (this issue). Baddeley (1986) suggested that recall depends on the speed of a covert verbal rehearsal process. Cowan and colleagues have argued that it may, but that recall also depends on the speed of some sort of short-term memory search process. Both of these processes could serve to refresh a short-term memory representation of list items. The memory search process would differ from rehearsal in that search would not require covert articulation and would proceed at the same rate regardless of the word length, perhaps based on a lexical representation. The main evidence for this is that the duration of silent pauses within correct spoken responses in memory span tasks depends upon the number of verbal items in the list but not upon the durations of those items (Cowan et al., 1994; Hulme, Newton, Cowan, Stuart, & Brown, 1999). Subjects may have to search through the list after each word in order to determine which word to recall next, and that search process would take longer when the list includes more words. This pattern of pauses in spoken recall resembles what is found in memory search tasks with a recognition probe, in which the reaction time depends upon the list length but not upon the word length (Chase, 1977; Clifton & Tash, 1973). Cowan et al. (1998) found that memory search and rapid speaking rates both were moderately related to memory span but were unrelated to each other.

We would suggest that either memory search or rehearsal processes (or both) can be used to refresh items in a list. Search processes would tend to be used when there is a strong lexical representation of each word, so that recall of the word is an all-or-none event. In contrast, when the lexical representation is weak, as when the items are pseudo-words, verbal rehearsal would have to be used because recall of one part of a pseudoword does not ensure recall of its remainder and rehearsal activates each part of the item separately, in turn. This type of rehearsal requires covert articulation of the list items and takes longer when the items are longer. These suggestions are supported to some

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extent by results showing that, in adults, immediate memory is correlated more with memory search measures when the items are words, but more with rapid articulation measures when the items are pseudowords (Hulme et al., 1999).

This theoretical view may help to explain some anomalies in the Cowan et al. (this issue) data pointed out by Service (this issue). The most important anomaly is that the recall of lists produced with short- versus long-duration cues does not yield comparable estimates of the duration of phonological short-term memory. After Baddeley, Thomson, and Buchanan (1975), those estimates can be obtained by assuming that articulation durations estimate covert rehearsal durations, and by therefore multiplying the level of recall (expressed in items) by the rapid-speaking rate (expressed in seconds per item) to produce a trace duration (expressed in seconds). However, Service showed that the estimate for the Cowan et al. (this issue) data was 2.2 s for slowly-spoken words as opposed to 1.6 s for quickly-spoken words. One suggestion she made is that the process of repeating words quickly, in the conditions with a short pronunciation cue, is effortful and detracts from the attention that can be devoted to recall. This view may have some merit, but we doubt that this can be an *entirely* correct explanation. In other, unpublished studies we have required adult subjects to repeat English digits as quickly as they could in their spoken recall, and this did not significantly alter the level of recall in comparison to a self-paced recall (Cowan et al., 1999a). We therefore doubt that rapid pronunciation harms recall for monosyllables. It is possible that the effort of rapid pronunciation harms recall for *disyllables*, which, when pronounced naturally, are much longer than the short cue duration of 300 ms.

These ideas can be examined within the theoretical framework offered above. For the small set of words in our study, the lexical representation should be very strong, so that refreshment of the memory trace can be accomplished via memory search rather than articulatory rehearsal. However, it seems reasonable to assume that this memory search process cannot take place during the presentation or recall of list items; and, in fact, there is evidence on pause durations that strengthens this assumption (Cowan et al., 1999b). Therefore, the search process would be limited to the silent time between words. As Service noted, given the paced nature of presentation and recall, there was more silent time available between short items than between long items, which would allow longer search processes for lists of shorter items.

Assume, for the time being, that a search process was used to activate items during the silent periods within the paced presentation and recall of words. The silent periods between items in presentation would be less critical because the list is not yet complete during those periods. During recall, each silent period can be estimated by subtracting the mean word pronunciation time from the 2.5 s recall period that was allowed for each word in the list. Assume further that the number of items that can be recalled is the number that can be refreshed through a memory search process during a single inter-item silent period between words spoken by the subject. Given these assumptions, it becomes possible to estimate the rate of memory search (in items per second) by dividing the number correct by the mean silent period. Applying this technique to lists with a uniform syllabic structure and uniform duration cues, this calculation yields fairly comparable estimates of the memory search rate for lists of monosyllables spoken quickly (1.7 items/s), monosyllables spoken slowly (1.5 items/s), disyllables spoken quickly (1.4 items/s) and disyllables spoken slowly (1.5 items/s).

Several theoretical points must be noted. First, these rates are too slow to reflect the same rapid search process that was identified by Sternberg (1966), unless perhaps search is carried out only intermittently within the context of list recall. Second, the rates indicate that the suspected disadvantage for disyllables spoken quickly is, apparently, minor. Third, the suggested recall strategy and resulting rate estimates may be valid only for experiments using slow, paced recall.

It seems possible that the silent periods during the *presentation* of the list also play a role. After most of the items in the list have been presented, silent periods between words in the presentation might be fairly useful for memory search. The importance of input periods can help to explain why no difference was obtained between mixed lists that began with short-duration words and ended with long words and those in which the long words came first. Lists that had the advantage of long silent intervals (i.e., short words) at the end of the presentation had the disadvantage of short silent intervals (long words) at the beginning of the recall period, and vice versa. In contrast, Cowan et al. (1992, Experiment 3) did find an advantage for lists in which the short words were recalled first (in both forward and backward recall), but the situation was quite different. The order of recall was not known until after the completion of the list, which might have led to a different strategy during input of the list, and recall was unpaced in that experiment.

With paced presentation, long words at input leave less time for refreshment of list items between these words. This fact could possibly account for word length effects obtained in studies in which the short and long words differed but were matched for the number of phonemes and syllables (Baddeley et al., 1975; Cowan et al., 1992). In these studies, the rate of presentation was held fixed at about 2 s/item, as in Cowan et al. (this issue). In contrast, the presentation rate was 1 sec/item in studies in which phonological complexity was controlled and duration effects were *not* obtained (Caplan, Rochon, & Waters, 1992; Caplan & Waters, 1994; Lovatt, Avons, & Masterson, 2000; Service, 1998). Perhaps this faster rate allows too little time to engage in a search/refreshment process at all. If this is the case, then the duration-based word length effect would not apply to ordinary span, which is typically collected at a 1 s/item presentation rate and unpaced recall in psychometric testing.

Although we have just suggested that the near-absence of a duration-based effect in Service (1998) may obtain because the inter-word intervals were too short for a memory search/refreshment process during input, other accounts certainly are possible. Cowan et al. (this issue) suggested that Service's Finnish subjects may have avoided rehearsal because it could obscure the durations of phonemes, which were pronounced in a short or long fashion within her pseudoword stimuli. Service (this issue) termed this "not a very convincing suggestion", for several reasons, but we are unsure. She pointed out that "recall rate for both lists with 'short' items and lists with longer items, consisting of both single and reduplicated phonemes, were similar, with spans over four items." The similarity of spans for lists with short and long items is exactly what would be expected with rehearsal blocked, according to Baddeley's (1986) notion that forgetting takes place either when there is no rehearsal, or during rehearsal as a function of the time since the last refreshment of an item. The fact that mean spans were over four items, longer than the spans for two-syllable pseudowords in English (Hulme, Maughan, & Brown, 1991), is

worth considering but difficult to evaluate given differences in procedure (with Service providing ten trials in a row per list length as opposed to four by Hulme et al.) and possible differences between studies in the word-likeness of the non-word stimuli (see Gathercole, 1995). Finally, Service remarked that "it would be very odd if languages developed phonological contrasts that could not be represented in the phonological loop." It need not be considered odd if non-phonological features can be used to supplement and disambiguate the contents of the phonological loop. In ordinary Finnish, presumably the vowel length need not be rehearsed because the semantic context usually would allow a regeneration of the correct vowel length at the time when recall of the linguistic material was needed. Nevertheless, across studies it seems more parsimonious to hypothesize that the presentation rate is the critical factor in whether a duration-based word length effect is obtained.

A central question that Service addressed is which technique more closely reflects the processes involved in ordinary recall. Service suggested that our task "seems to depend on an auditory image that represents absolute time. This could push subjects to rely on sensory memory to a greater extent than in a conventional word-length experiment, in which case the duration effect might reflect the workings of this memory system rather than the phonological loop." Although this is a real possibility, it could equally be said that the need to retain vowel lengths in non-words could require an auditory image in Service's (1998) study. Perhaps these questions could be investigated with the silent visual presentation of stimuli.

In sum, we have proposed multiple mechanisms of duration-based word length effects. They might occur during a rehearsal process if the rehearsal cycle is longer for long words, as Baddeley (1986) proposed. They also might occur if the presentation of long words leaves less unfilled time for memory search between words, either during presentation or during recall. Other output-based effects are also possible (Cowan et al., 1992). Effects of the time available for memory search could be investigated by keeping the interword interval rather than the stimulus onset asynchrony constant. We thus have identified various factors that may be critical in further research with these two intriguing techniques for examining word length effects, and we hope to see a resolution within several years.

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