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# Serial position, output order, and list length effects for words presented on smartphones over very long intervals

Cathleen Cortis Mack[a], Caterina Cinel[a], Nigel Davies[b], Michael Harding[b], Geoff Ward[a,*]

[a] Department of Psychology, University of Essex, United Kingdom
[b] Department of Computing and Communications, University of Lancaster, United Kingdom

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ABSTRACT

Three experiments examined whether or not benchmark findings observed in the immediate retrieval from episodic memory are similarly observed over much greater time-scales. Participants were presented with experimentally-controlled lists of words at the very slow rate of one word every hour using an iPhone recall application, RECAPP, which was also used to recall the words in either any order (free recall: Experiments 1 to 3) or the same order as presented (serial recall: Experiment 3). We found strong temporal contiguity effects, weak serial position effects with very limited recency, and clear list length effects in free recall; clear primacy effects and classic error gradients in serial recall; and recency effects in a final two-alternative forced choice recognition task (Experiments 2 and 3). Our findings extend the timescales over which temporal contiguity effects have been observed, but failed to find consistent evidence for strong long-term recency effects with experimenter-controlled stimuli.

## Introduction

The presentation and testing of word lists has been a fundamental source of empirical data in the study of the psychology of memory (e.g., Anderson, Bothell, Lebiere, & Matessa, 1998; Baddeley, 1986; Baddeley, Eysenck, & Anderson, 2014; Crowder, 1976; Greene, 1992; Kahana, 2012; Murdock, 1974; Neath & Surprenant, 2003). Using word lists, the experimenter can exercise near complete control over the selection and ordering of the experimental stimulus set, and can exert close control over the timing and procedure used at study and test. This method has been widely used to study memory in tasks such as free recall (e.g., Murdock, 1962), serial recall (e.g., Drewnowski & Murdock, 1980), recognition memory (e.g., Ratcliff, Clark, & Shiffrin, 1990), and tests of implicit memory (e.g., Hayman & Tulving, 1989).

The vast majority of laboratory studies present lists of words at rates of one item every few seconds, a convenient rate if multiple trials and/or conditions are to be studied within a single experimental session. The aim of the current set of experiments is to demonstrate the effectiveness of a new way of conducting list learning studies outside of the laboratory. To this end, we report three experiments that presented multiple, experimenter-controlled lists of stimuli for memory tests with inter-stimulus intervals that are far greater than those typically used (presentation rates of 1 word per hour). Although we concentrate primarily on the free recall task (Experiments 1–3), we have also examined recognition memory (Experiments 2 and 3) and serial recall (Experiment 3).

In the free recall task, participants are presented with a list of words, one at a time, and at the end of the list, they must try to recall as many of the list items as they can, in any order that they like. Theories of free recall have sought to explain the characteristic serial position curves and the regularities in the output order in the task. The serial position curve refers to the graph relating the probability of recall with the position on the experimenter's list. Specifically, results from laboratory studies have shown that participants tend to recall more words from early list positions (*the primacy effect*) and later list positions (*the recency effect*) than the middle of the list (sometimes known as the *asymptote*) such that there is a U-shaped serial position curve (e.g., Deese, 1957; Jahnke, 1965; Murdock, 1962).

Considering the output order in the task, theories seek to explain the characteristic shape of the *Probability of First Recall* (PFR) data and the *temporal contiguity effect*. Regarding the PFR, participants tend to initiate recall of a long list of words with one of the last few list items (Hogan, 1975; Howard & Kahana, 1999; Laming, 1999), although there is also a tendency to initiate recall of a shorter list with the first list item (Ward, Tan, &

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* Corresponding author at: Department of Psychology, University of Essex, Wivenhoe Park, Colchester, Essex CO4 3SQ, United Kingdom.

*E-mail address:* gdward@essex.ac.uk (G. Ward).

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Grenfell-Essam, 2010). The *temporal contiguity effect* refers to the tendency to output successive items from nearby serial positions, with an asymmetric bias to recall in forward order (Howard & Kahana, 1999; Kahana, 1996). The standard methodology is to calculate the *Conditionalized Response Probabilities* (CRPs) of making transitions of different lags. The lag refers to the difference between the serial position of the word recalled at output position $j + 1$ and the serial position of the word recalled at output position $j$. A small absolute value of lag refers to successive recalls from near neighbours in the experimenter's list; a large absolute value of lag refers to successive recalls from items from more distant serial positions. A positive lag refers to successive recalls that proceed in a forward direction (in the same direction as input); a negative lag refers to successive recalls that proceed in a backward direction (a later item in the list is output before an earlier list item). For each participant and each list, the observed number of transitions at each lag is divided by the number of opportunities that there were for making such transitions. This calculation takes into account that there are many more opportunities to make transitions of smaller than larger lag, and it is also assumed that participants should not recall items that have already been recalled. The Lag-CRP analyses tend to show asymmetric lag recency effects: transitions are most frequently made to nearby serial positions, and there is a preference to output successive words in forward serial order, such that the most frequent lag is +1. This asymmetric lag recency function has been shown in a wide range of data sets including continual distractor free recall (Howard & Kahana, 1999) and is regularly observed across most, if not all, individuals (Healey & Kahana, 2014).

Laboratory studies examining the serial position curve contributed greatly to the development of classic dual-store theories of free recall (e.g., Atkinson & Shiffrin, 1971; Glanzer, 1972; Raaijmakers & Shiffrin, 1981) that assumed separate short-term store (STS) and long-term store (LTS) memory mechanisms. These accounts assumed that the primacy effect reflected the additional rehearsals in STS that were afforded to early list items and which strengthened associations in LTS (e.g., Rundus, 1971). The recency effect was assumed to reflect participants' preference to initiate recall by outputting the contents of STS, which most likely contained the end of list items. Subsequently, it has been argued that the temporal contiguity effect could also be explained if one assumed that (1) inter-item associations were formed between items that reside concurrently in STS (e.g., Raaijmakers & Shiffrin, 1981) and (2) neighbouring items in the experimenter's list were most likely to co-reside in STS (see Kahana, 1996). Many contemporary theorists continue to ascribe a role for STS in immediate free recall (e.g., Davelaar, Goshen-Gottstein, Ashkenazi, Haarman, & Usher, 2005; Lehman & Malmberg, 2013; Mensink & Raaijmakers, 1988, 1989; Unsworth & Engle, 2007), but it is now widely accepted that serial position effects and temporal contiguity effects can additionally occur using methodological variants in the laboratory and timescales for real-world stimuli for which an STS explanation of primacy, recency and contiguity effects is untenable.

For example, in the continual distractor free recall task, participants see lists of to-be-remembered (TBR) words and must perform a rehearsal-preventing distractor task after each and every list item, including the last. If the only method for generating primacy effects, recency effects, and contiguity effects was via STS, then these effects should be eliminated in the continual distractor task, because the contents of STS should be displaced by the contents of the distractor task that is presented after each item. Nevertheless, primacy and recency effects (e.g., Baddeley & Hitch, 1974; Bhatarah, Ward, & Tan, 2006; Bjork & Whitten, 1974; Howard & Kahana, 1999; Tzeng, 1973; Watkins, Neath, & Sechler, 1989) are observed using this variant of free recall, in which the words are typically presented at relatively slow laboratory rates of 1 word every 5–20 s.

Temporal contiguity effects are also observed in the continual distractor free recall task (e.g., Bhatarah et al., 2006; Howard & Kahana, 1999). Thus, participants in the continual distractor task tend to output successive responses that come from neighbouring serial positions, and there is a forward-ordered bias. This occurs despite the reduction in opportunity to co-rehearse words, since the STS must be used to carry out the distractor task in between each list item. Moreover, Howard, Youker, and Venkatadass (2008) have shown evidence for long-range contiguity effects over several hundred seconds. In their study, participants were presented and tested on 48 lists of words. At the end of the experimental session, participants were given a surprise test of final free recall and asked to recall all the list items from all 48 lists. Despite the lists being separated by about 50 s, Howard et al. observed that there was significant temporal contiguity effects both within-lists and across-lists in the test of final free recall. Similar results have been obtained by Unsworth (2008) in tests of final free recall, who also showed that when participants recalled successive outputs from different lists, they were more likely to transition to an item from a list that had been presented in close temporal proximity to the most recently recalled item than to an item from a more distant list. It should be noted that in both these final free recall data sets, the observed temporal contiguity effect between lists was symmetrical rather than asymmetric: participants were more likely to transition to words from neighbouring lists than to more distant lists, but they were no more likely to transition in forward order than backward order.

Using real-world stimuli, recency effects have also been observed over very long time-scales that clearly rule out an STS interpretation. For example, recency effects occur in the recall of autobiographical events (e.g., Crovitz & Shiffman, 1974; Moreton & Ward, 2010; Rubin, 1982, 1996) that were self-reported and self-dated over days, months, and years. Long-term recency effects have also been observed for free recall of similar events spanning days and weeks, such as where one parked one's car (Pinto & Baddeley, 1991) and opponents of rugby matches (Baddeley & Hitch, 1977). Finally, serial position curves of semantic memory have also been observed in the recall and ordering of the US (Neath, 2010; Roediger & Crowder, 1976) and Canadian (Neath & Saint-Aubin, 2011) Presidents. Using real-world stimuli, Moreton and Ward (2010) have also showed long-term contiguity effects in self-reported and self-dated autobiographical memories. Note however that these experiments had far less control of the allocation of the stimuli across all serial positions, and in some cases, we do not have a complete record of the set of stimuli, making it difficult to assess the accuracy of recall.

Some researchers (e.g., Brown, Neath, & Chater, 2007; Howard & Kahana, 2002; Tan & Ward, 2000) have abandoned the distinction between short-term and long-term memory, and have taken the ubiquity of serial position curves and/or temporal contiguity effects across methodologies and timescales as evidence that episodic memory should be viewed as a continuum, with the same principles applied to the retrieval of all list items. One influential empirical finding is the ratio rule (e.g., Bjork & Whitten, 1974; Crowder, 1976, 1993), which proposes that the probability that a recency item will be recalled in free recall can be predicted by the ratio ($\Delta t/T$) of the inter-presentation interval ($\Delta t$) and the retention interval ($T$). A number of studies have provided evidence consistent with the ratio rule. These studies have systematically varied the inter-presentation interval ($\Delta t$) and the retention interval ($T$) *across lists*, often by requiring participants to perform a mental arithmetic or digit shadowing task in the intervals between the TBR words (e.g., Glenberg, 1984; Glenberg, Bradley, Kraus, &