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Temporal isolation effects in immediate recall

Rachel Grenfell-Essam[a,*], Geoff Ward[b,*], Cathleen Cortis Mack[b]

[a] University of Suffolk, UK
[b] University of Essex, UK

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ABSTRACT

Three experiments examined temporal isolation effects (TIEs), the recall advantage for stimuli separated by increased inter-stimulus intervals. Prior research suggests that TIEs are observed in immediate free recall (IFR) using longer lists, but are weaker or absent in immediate serial recall (ISR) using shorter lists. Using digit-filled intervals to reduce rehearsal, IFR and ISR benefitted overall from longer pre-item intervals and shorter post-item intervals, using lists of 7, 17, and 5 words (Experiments 1–3, respectively). Consistent with a grouping account, the first words recalled were often preceded by longer pre-item intervals and transitions tended to be between neighboring items separated by shorter intervals. Using 7-item lists with unfilled intervals (Experiment 3), both IFR and ISR benefitted from longer post-item intervals (possibly due to rehearsal), and once the first responses were removed, there was no effect of pre-item interval on either task. These similar findings encourage the theoretical integration of ISR and IFR.

The present research is motivated by two main aims. First, we seek to continue an on-going line of research examining the similarities and differences between two widely-used and highly-influential tests of immediate memory: immediate free recall (IFR) and immediate serial recall (ISR). Our motivation within this first aim is to seek evidence for greater theoretical integration between these two literatures: evidence supporting integration would be provided to the extent that recall performance in the two tasks is similar when the two tasks are compared under similar methodologies, list lengths, and scoring systems. Second, we seek to examine the characteristics and cause of the *Temporal Isolation Effect* (TIE), the memorial advantage for items that are temporally isolated at encoding, and so are more temporally discriminable from their immediate neighbours at retrieval. Our motivation within this second aim is to better understand the variation in the magnitudes of TIEs that have been observed in prior research, particularly given that prior research suggests that TIEs may be stronger in IFR but may be weaker, or even absent, in ISR.

We first summarize the relationship between IFR and ISR and consider the similarities and differences in the methodologies and typical research findings from the two tasks. In the IFR task, participants are presented with a long list of between 10 and 40 items, one at a time, and after the last list item, they must try to recall as many items as they can and are free to recall in any order that they wish. Each item is scored as correct if it is output at any time during the recall period for that trial (*free recall* or FR scoring). Typically, IFR performance is dominated by strong and extended recency effects with limited primacy (e.g., Murdock, 1962). In the ISR task, participants are presented with a shorter list of between 5 and 8 items, one at a time, and after the last item, they are required to recall as many items as they can in the same serial order as they were presented. Each item is typically scored as correct if it is output in the same serial position as it had been presented (*serial recall* or SR scoring). Typically, ISR performance is dominated by strong and extended primacy effects with very limited recency (e.g., Drewnowski & Murdock, 1980).

Ward, Tan, and Grenfell-Essam (2010) have outlined how the recall performance in the two tasks has been largely explained by different sets of theories. Theories of IFR (e.g., Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Farrell, 2010; Howard & Kahana, 2002; Laming, 2006, 2010; Lehman & Malmberg, 2013; Lohnas, Polyn, & Kahana, 2015; Metcalfe & Murdock, 1981; Polyn, Norman, & Kahana, 2009; Raaijmakers & Shiffrin, 1981; Sederberg, Howard, & Kahana, 2008; Tan & Ward, 2000; Unsworth & Engle, 2007) have tended to focus on explanations of the strong recency effects in IFR and have said relatively little about ISR performance, whereas theories of ISR (e.g., Anderson & Matessa, 1997; Baddeley, 1986, 2007, 2012; Botvinick & Plaut, 2006; Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1999, 2006; Farrell & Lewandowsky, 2002; Henson, 1998; Lee & Estes, 1981; Lewandowsky & Farrell, 2008; Lewandowsky & Murdock, 1989; Nairne,

* Corresponding authors at: School of Psychology and Education, University of Suffolk, Waterfront Building, Ipswich, Suffolk IP4 1QJ, UK (R. Grenfell-Essam). Department of Psychology, University of Essex, Wivenhoe Park, Colchester, Essex CO4 3SQ, UK (G. Ward).
E-mail addresses: R.Grenfell-Essam@uos.ac.uk (R. Grenfell-Essam), gdward@essex.ac.uk (G. Ward).

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1988, 1990; Neath, 2000; Oberauer & Lewandowsky, 2008; Page & Norris, 1998, 2003) have tended to focus on explaining primacy effects in ISR and have said relatively little about IFR performance. The case for theoretical integration is presented in the next section.

Toward a theoretical integration of IFR and ISR

In recent years, we have argued that there are more similarities than previously thought between IFR and ISR, and these similarities are more apparent when the two tasks are examined using similar methodologies, list lengths, and scoring systems. Prior research had suggested that the two tasks differed in their serial position curves, output orders, and their sensitivity to different variables, but more recent evidence suggests greater similarities once the two tasks are compared under more similar methodologies. We summarize the three historic differences and their more recent evaluations in the following three paragraphs.

A first historic difference between IFR and ISR is that the two tasks are characterized by different-shaped serial position curves. The serial position curves in IFR are typically dominated by large and extended recency effects with reduced primacy effects, but the serial position curves in ISR are dominated by large and extended primacy effects with very reduced recency effects. However, Ward et al. (2010) showed that the serial position curves were greatly affected by where participants initiated their recall (the Probability of First Recall, PFR), and this in turn was heavily influenced by the list length (also found in Cortis, Dent, Kennett, & Ward, 2015; Grenfell-Essam & Ward, 2012, 2015; Grenfell-Essam, Ward, & Tan, 2013). Participants undertaking IFR of long lists tended to initiate recall with one of the last few list items, a finding consistent with earlier analyses (e.g., Hogan, 1975; Howard & Kahana, 1999; Laming, 1999), but when participants were required to recall a far shorter list of, say, four items for IFR, they typically initiated recall with the first list item (similar to ISR). Similarly, Ward et al. found that participants could not always recall the first item on tests of ISR with longer lists, and on these trials often initiated recall with one of the last few words (similar to IFR). Moreover, Ward et al. showed that where one starts their recall strongly influences the resultant serial position curve: participants starting with the first list item tend to recall other early list items and show reduced recency effects; whereas participants starting with one of the last four items tend to recall other recency items and show reduced primacy effects. Thus, the differences in list length contribute to the historic differences that have been observed in the serial position curves in IFR and ISR.

A second historic difference between IFR and ISR concerns the output order in the two tasks. Although participants in ISR are instructed to recall in forward serial order; participants in IFR are free to recall in any order. Nevertheless, there is growing acceptance that participants in IFR tend to transition between successive outputs in forward order, even though forward-ordered recall is not a task requirement in IFR (e.g., Bhatarah, Ward, & Tan, 2008; Grenfell-Essam & Ward, 2012; Ward et al., 2010, see also Beaman & Jones, 1998; Golomb, Peelle, Addis, Kahana, & Wingfield, 2008; Howard & Kahana, 1999; Kahana, 1996; Klein, Addis, & Kahana, 2005). Indeed, participants tend to encode (Bhatarah et al., 2008; Grenfell-Essam & Ward, 2012) and rehearse (Bhatarah, Ward, Smith, & Hayes, 2009) the list items in IFR and ISR in similar ways. As mentioned in the preceding paragraph, the forward-ordered nature of recall in both tasks exaggerates the PFR differences that occur with increasing list length, and contributes greatly to the historic differences that have been observed in the serial position curves in IFR and ISR.

A final historic difference between IFR and ISR concerns the sensitivity of the memory span in ISR and the recency effect in IFR to different theoretically important variables. It is well-known that ISR is highly sensitive to speech-based variables such as phonological similarity (Baddeley, 1966), word length (Baddeley, Thomson, & Buchanan, 1975), articulatory suppression (Murray, 1967, 1968), and irrelevant speech (Salamé & Baddeley, 1982), whereas it has been argued (e.g., Baddeley, 1976, pp. 180–184) that the recency effect in IFR is not selectively sensitive to these variables. However, subsequent research has shown that when both tasks are compared using identical list lengths, methodologies and scoring systems, both tasks are sensitive to phonological similarity (Spurgeon, Ward, & Matthews, 2014), word length (Bhatarah et al., 2009), and articulatory suppression (Bhatarah et al., 2009) in similar ways (for comparable effects of irrelevant speech on IFR and ISR, see Beaman & Jones, 1998). In a recent example, Grenfell-Essam, Ward, and Tan (2017) showed that the magnitude and extent of the modality effect in IFR and ISR were largely attributable to the list length used: modality effects of smaller magnitude but extending over many terminal serial positions were observed with longer lists (as typically observed in IFR), but modality effects of greater magnitude but extending over only a very limited range of terminal serial positions were observed with shorter lists (as typically observed in ISR).

This growing body of work suggests that many of the differences that were previously assumed to be attributable to different theoretical mechanisms or different encoding strategies, were actually more attributable to the different list lengths that were used and retrieval strategies reflecting task instructions. When shorter list lengths (that are characteristic of ISR) are used, both tasks show more “ISR-like” performance; whereas when longer list lengths (that are characteristic of IFR) are used, both tasks show more “IFR-like” performance. Consistent with the motivation behind this first aim, a number of recent attempts have been made to model both tasks within a single unified theory (e.g., Brown, Neath, & Chater, 2007; Farrell, 2012; Grossberg & Pearson, 2008).

The temporal isolation effect in IFR and ISR

The TIE refers to the recall advantage for items that are more temporally isolated at encoding and so are more temporally discriminable from their immediate neighbours at retrieval. The finding is of theoretical interest because a number of theories of memory explicitly propose (or implicitly assume) that items may be organized in memory along a temporal dimension, and that the temporal dimension can be used at retrieval to help discriminate to-be-remembered list items (e.g., Baddeley, 1976; Bjork & Whitten, 1974; Brown et al., 2000; Brown et al., 2007; Brown, Vousden, & McCormack, 2009; Crowder, 1976, 1982; Glenberg, 1987; Glenberg & Swanson, 1986; Howard, Shankar, Aue, & Criss, 2015; Murdock, 1960; Neath, 1993).

A telephone pole analogy (Crowder, 1976) is often used to illustrate the key idea of temporal distinctiveness (Bjork & Whitten, 1974). In this analogy, one is encouraged to imagine looking back along a straight road or railway track that extends far out to the horizon and which has telegraph poles spaced at regular intervals along its length. Through perspective, the telegraph poles that are closer to the observer will appear larger and more widely spaced, whereas those that that are closer to the horizon will appear smaller and more tightly grouped together. If one considers that the evenly-spaced telegraph poles are now to-be-remembered list items presented at regular intervals and the straight road is the distribution of items along a temporal dimension, then temporal distinctiveness accounts assume that the subjective dimension of time is logarithmically compressed (e.g., Brown et al., 2007), such that more recent events are more temporally discriminable (analogous to the apparently widely-spaced nearby poles) whereas far earlier events are in a crowded region, and are far less temporally discriminable (analogous to the apparently clustered tightly-spaced distant poles).

Although the analogy was first proposed to help explain the magnitude of recency effects in free recall given different inter-stimulus intervals and retention intervals (e.g., Bjork & Whitten, 1974; Crowder, 1976; Glenberg, Bradley, Kraus, & Ranzaglia, 1983; Nairne, Neath, Serra, & Byun, 1997), temporal distinctiveness accounts assume that there will be a recall advantage for any item that is temporally isolated,

Table 1
Methodological details of research using predictable temporal schedules.

Experiment	List length	Stimulus type	Presentation Schedule	Inter-stimulus stimuli	Inter-stimulus durations	Rehearsal able to happen?	TIE found?
ISR with Predictable temporal schedule							
Corballis (1966)	9	Digits	Increasing and decreasing	Unfilled	500–1900 ms	Yes	Yes – limited to last 2 SPs only
Lewandowsky et al. (2007, Experiment 1)	7	Consonants	Increasing, decreasing, and constant	Unfilled	50–1200 ms (458 ms for constant)	Half the participants performed AS	Yes
Lewandowsky et al. (2007, Experiment 2)	7	Consonants	Increasing and decreasing	Unfilled	50–1200 ms	Half the participants performed AS	Yes
Neath and Crowder (1996, Experiment 2)	5	Words	Increasing, decreasing, and constant	Unfilled	40–400 ms (550 ms for constant)	Unlikely	Yes
Neath and Crowder (1996, Experiment 3)	5	Words	Increasing, decreasing, and constant	Unfilled	40–234 ms (550 ms for constant)	Unlikely	Yes
Neath and Crowder (1996, Experiment 4)	5	Words	Increasing, decreasing, and constant	Unfilled	40–234 ms (550 ms for constant)	Unlikely	Yes
Welte and Laughery (1971)	9	Digits	Increasing and decreasing	Unfilled	500–1900 ms	Yes	Yes
IFR with Predictable temporal schedule							
Brown et al. (2006, Experiment 1)	17	Words	Increasing and decreasing	Digits	0–3500 ms	No	Yes
Neath and Crowder (1990, Experiment 2)	5	Consonants	Increasing, decreasing, and constant	Digits	0–2000 ms (1000 ms for constant)	No	Yes
Neath and Crowder (1990, Experiment 3	5	Word pairs	Increasing, decreasing, and constant	Mathematical addition sums	0–32 s	Unlikely	Yes
Neath and Crowder (1996, Experiment 1)	5	Words	Increasing, decreasing, and constant	Unfilled	40–400 ms (550 ms for constant)	Unlikely	Yes
Polyn et al. (2019)	17	Words	Cyclically increasing and decreasing	Mathematical addition sums	6–23 s	Unlikely	No

Note: TIE refers to Temporal Isolation Effect and AS refers to Articulatory Suppression.

as the event will occupy a less crowded area of psychological space and so will be more temporally discriminable.

Early studies varied the ratio between the inter-stimulus intervals and the retention intervals (e.g., Nairne et al., 1997), isolated individual items (e.g., Glenberg & Swanson, 1986), or varied the schedule of inter-stimulus intervals in predictable ways by increasing or decreasing inter-stimulus intervals systematically across serial positions (e.g., Brown, Morin, & Lewandowsky, 2006, Experiment 1; Crowder & Neath, 1991; Neath & Crowder, 1990, 1996; Welte & Laughery, 1971). As Table 1 shows, when the inter-stimulus interval is varied predictably, there are clear effects of presentation schedule for both ISR and IFR. One exception comes from a study by Polyn, Kragel, McCluey, and Burke (2019) who found no recall benefit for temporally isolated items using lists of 15 words where the inter-stimulus intervals expanded and contracted in a cyclical manner. Nevertheless, Lewandowsky, Wright, and Brown (2007) have argued that when predictable schedules are used, then even findings that are consistent with a TIE could be alternatively explained by differential rehearsal and the strategic encoding of slower items.

Critically for the current studies, differences between IFR and ISR emerge in later studies in which the inter-stimulus intervals are unpredictable (through randomization) and when the opportunity to rehearse is greatly attenuated (see Table 2). To date, there have many failures to find significant TIEs using randomized inter-stimulus intervals using ISR of shorter lists (e.g., Lewandowsky & Brown, 2005; Nimmo & Lewandowsky, 2006; Parmentier, King, & Dennis, 2006) but the effect has been observed in IFR of longer lists (e.g., Brown et al., 2006; Experiment 2, but see also Polyn et al., 2019). One possibility is that the effect exists in ISR but is at a much smaller magnitude than in IFR (Morin, Brown, & Lewandowsky, 2010). More generally, stronger TIEs have been observed in tasks where participants have some freedom to recall using their preferred output order, but not in related tasks when the output order is prescribed (e.g., Geiger & Lewandowsky, 2008; Lewandowsky, Brown, & Thomas, 2009; Lewandowsky, Nimmo, & Brown, 2008). Lewandowsky et al. (2009) examined an unconstrained reconstruction of order task using a 7-item list with unpredictable inter-stimulus intervals where participants engaged in articulatory suppression throughout presentation, retention interval and reconstruction. They found participants tended to initiate reconstruction with temporally isolated items and engage in forward ordered reconstruction.

The current research re-examines the extent to which there are replicable differences in the magnitude of TIEs in IFR and ISR. We note that (1) there are not many cases of the TIE with randomized intervals in IFR; (2) the magnitude of the TIEs in IFR and ISR have rarely been compared under similar methodologies within the same experiment, and (3) we note that ISR is often examined using shorter lists with unfilled temporal intervals and IFR is typically examined using longer lists with distractor-filled intervals.

To these ends, we report one experiment (Experiment 1, list length 7) examining the effects of temporal isolation using a shorter list length that is more commonly associated with ISR, and a second experiment (Experiment 2, list length 17) using a longer list length that is more commonly associated with IFR. In both experiments and both tasks we use digit-filled intervals to reduce additional rehearsal during the inter-stimulus interval. As discussed earlier, previous research has shown that list length can play an important role on the PFR, the resultant serial position curves, and the magnitude and extent of different variables in the two tasks (such as modality effects, Grenfell-Essam et al., 2017). It may be that some differences in TIEs that have been previously attributed to different tasks, may rather be attributable to differences in the list lengths and the methods that have been used.

In both experiments, we manipulated temporal isolation in a pseudo-random manner such that the schedules of inter-stimulus intervals were unpredictable, and we filled the inter-stimulus intervals with a rehearsal-attenuating task (digit naming). In both experiments, we directly

Table 2
Methodological details of research using randomized temporal schedules.

Experiment	List length	Stimulus type	Presentation Schedule	Inter-stimulus stimuli	Inter-stimulus durations	Rehearsal able to happen?	TIE found?
ISR with Randomized temporal schedule							
Farrell (2008, Experiment 2)	6	Digits	Random	Unfilled	100–1200 ms	Yes	No
Farrell (2008, Experiment 3)	6	Digits	Random	Unfilled	0–1500 ms	Yes	Yes - weak effect
Farrell et al. (2011, Experiment 1)	8	Digits	Random	Unfilled	100–1500 ms	Yes	Yes - weak effect
Farrell et al. (2011, Experiment 2)	8	Digits	Random	Unfilled	100–1000 ms	Yes	Yes - weak effect
Lewandowsky and Brown (2005, Experiment 1)	9	Consonants	Random	Unfilled	50–937 ms	Yes	Yes
Lewandowsky and Brown (2005, Experiment 2)	9	Consonants	Random	Unfilled	50–937 ms	No - performed AS	No
Lewandowsky, Brown, Wright, and Nimmo (2006, Experiment 1)	7	Consonants	Random	Unfilled	50–1200 ms	Half the participants performed AS	No.
Morin et al. (2010, Experiment 2)	7	Words	Random	Digits	550–4950 ms	Yes	Yes
Nimmo and Lewandowsky (2005)	7	Consonants	Random	Unfilled	50–4000 ms	Half the participants performed AS	No
Nimmo and Lewandowsky (2006, Experiment 1)	7	Consonants	Random	Unfilled	450–4400 ms	Yes	No
Nimmo and Lewandowsky (2006, Experiment 2)	7	Consonants	Random	Unfilled	125–4000 ms	Yes	No
Parmentier et al. (2006)	7	Digits	Random	Unfilled	50–950 ms	Yes	No
IFR with Randomized temporal schedule							
Brown et al. (2006, Experiment 2)	17	Words	Random	Digits	0–3500 ms	No	Yes

Note: TIE refers to Temporal Isolation Effect and AS refers to Articulatory Suppression.

contrasted performance of a group who performed IFR with a group who performed ISR using otherwise identical methodologies. We further explore the role of output order and the requirement to allocate responses to serial positions, by including a third group of participants in each experiment using a variant of ISR that we here call ISR-free (but is sometimes called free-ordered or free output ordered serial recall) in which participants are required to recall the items in their correct serial position but are free to output the items in whatever order they wish. This is achieved by requiring participants to write (in any temporal order that they wish) the recalled items in the row of a numbered lined response grid that corresponds to the respective input position (for other data using this task, see Tan & Ward, 2007; Ward et al., 2010; Welte & Laughery, 1971). To anticipate the findings of Experiments 1 and 2, we found broadly similar patterns of TIEs in ISR and IFR when the two tasks were examined using similar methodologies.

A final experiment, Experiment 3 sought to compare TIEs in ISR and IFR using both the digit-filled intervals (used in IFR) and unfilled temporal intervals (used in ISR). We chose list lengths that we hoped would produce the characteristic extended primacy effects in ISR. We replicated our earlier findings in IFR and ISR using digit-filled intervals when we reduced the list length to 5 words, but we still obtained only modest primacy. However, we managed to obtain characteristic bowed serial position curves in IFR and extended primacy effects in ISR using 7-word lists using unfilled temporal intervals (e.g., Farrell, Wise, & Lelièvre, 2011). In this latter method, (once the initial response was removed) we again showed similar TIEs in IFR and ISR. Specifically, when rehearsal was not prevented, both tasks showed no effect of the unfilled pre-item interval on recall, but a recall advantage of larger unfilled post-item intervals.

Experiment 1

In Experiment 1, we examined TIEs in IFR, ISR, and ISR-free using lists of 7 words. The inter-stimulus intervals were manipulated by requiring participants to say aloud 0, 1, 3 or 7 digits before and after each and every list item. As there was an inter-stimulus interval before the first word, there was a total of 8 intervals in each list. There were two repetitions of each digit length such that each list was filled with every ordered combination of 0, 0, 1, 1, 3, 3, 7 and 7 digits. Previous work with short lists has typically used ISR and found little (Morin et al., 2010) or no TIEs (e.g., Lewandowsky & Brown, 2005; Nimmo & Lewandowsky, 2006; Parmentier et al., 2006), but the effect of TIE has been observed in IFR using longer list lengths (e.g., Brown et al., 2006).

If the magnitude of the TIEs was determined by the different task demands, then one might expect larger effects of TIEs in IFR relative to ISR. The comparison of the IFR and ISR groups with recall performance in the ISR-free group would further allow us to determine whether it was the requirement to recall in strict forward order that reduces the TIE (in which case ISR-free would show TIEs more comparable with IFR than ISR, for a related comparison with reconstruction of order, see Lewandowsky et al., 2008) or whether it is the requirement to specify the serial position of the recalled items that reduces the TIE (in which case ISR-free would show TIEs more comparable with ISR than IFR). By contrast, if the magnitude of the TIEs in previous research was instead determined by the list length, then one might expect similar small, or non-significant, effects of TIEs in all three tasks. Moreover, if similar findings across the three tasks were observed when the methodology, list length and scoring systems were equated then this would aid with the theoretical integration of ISR and IFR (Grenfell-Essam & Ward, 2012; Ward et al., 2010).

Method

Participants

A total of 105 students from the University of Essex took part in this experiment and received either a course credit or a small payment (£6). The experiment lasted approximately 60 min.

Materials and apparatus

A subset of 525 words were randomly selected for each participant from the 1000 words of the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982). The words and digits were presented in 60-point Times New Roman font. The materials were presented on an Apple eMac computer monitor using the Supercard 4.6 application. Participants' output orders were recorded via a Logitech USB Headset 4.330 using the Audacity application.

Design

The experiment used a mixed design. The between-subjects independent variable was task type with three levels (IFR, ISR, or, ISR-free). There were two within-subjects independent variables. The first within-subjects independent variable was the temporal isolation of the words. The temporal isolation interval preceding a word is termed the *pre-item interval* with four levels (0, 1, 3, and 7 digits). The temporal isolation interval following a word is termed the *post-item interval* with four levels (0, 1, 3, and 7 digits). The sum of the pre-item interval and post-item interval is termed the *total temporal isolation interval* with 10 levels (0.00, 0.55, 1.10, 1.65, 2.20, 3.30, 3.85, 4.40, 5.50, and 7.70 s). The second within-subjects independent variable was the serial position (SP) of the words with seven levels (SPs 1–7). The main dependent variables were the proportion of words recalled in any order (*FR scoring*) and in the correct serial position (*SR scoring*).

Procedure

Participants were randomly allocated to one of three groups, each containing 35 participants: IFR, ISR, or ISR-free. Participants were tested individually, and informed that they would be shown three practice lists of seven words each followed by 72 experimental lists of words. The experimental trials were split into two equal blocks of 36 trials each.

There were eight inter-stimulus intervals on each trial, one before and after each of the seven words. These 8 intervals were assigned 0, 0, 1, 1, 3, 3, 7 and 7 digits in different permutations. A complete set of every permutation of the inter-stimulus intervals provided 2520 unique sequences. Each participant was pseudo-randomly allocated 72 of these sequences such that over the 35 participants in each task group all 2520 sequences were assigned. A pseudo-random allocation was used to ensure that each participant experienced every combination of pre-item interval and post-item interval between 11 and 25 times at every serial position in the list. The average number of repetitions was 18. For example, between the first and second words (pre-item interval 2) and between the second and third words (post-item interval 2) every possible digit combination (0 0; 0 1; 0 3; 0 7; 1 0; 1 1; 1 3; 1 7; 3 0; 3 1; 3 3; 3 7; 7 0; 7 1; 7 3; and 7 7) occurred at least eleven times. The three practice trials consisted of three randomly assigned temporal isolation sequences that were not repeated in their experimental trials. For all participants, the order of their assigned temporal isolation sequences was randomised over the whole experiment.

Each trial started with a blank screen for 1300 ms. Following this a fixation cross was displayed for 700 ms: 550 ms on-screen and 150 ms off-screen. The fixation cross could be followed by 0, 1, 3, or 7 digits. Each digit was displayed for 550 ms: 400 ms on-screen and 150 ms off-screen. Each word was displayed for 700 ms: 550 ms on-screen and 150 ms off-screen. Participants were instructed to read aloud both the digits and the words as they were presented. After the presentation of the last item, a white box appeared in the centre of the screen indicating the start of recall. Participants were instructed to write down as many of the seven words as they could on the paper response sheet, while simultaneously vocalising their output. Output was vocalised in all three groups to enable spoken output order in the ISR-free trials to be established, to verify that participants in the ISR group adhered to the instructions to output only in a forward direction, and in the IFR group

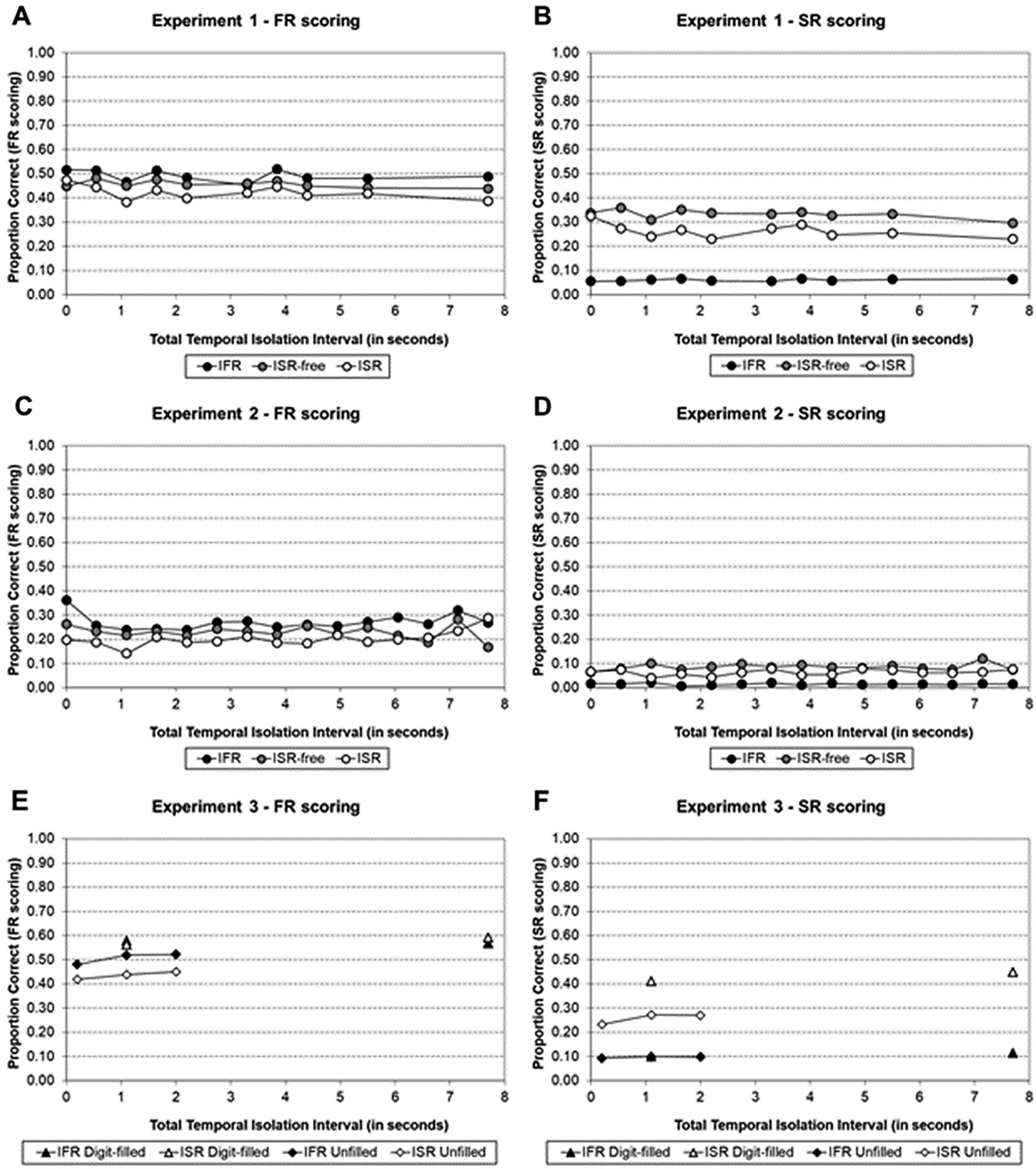

Fig. 1. Mean proportion of words recalled as a function of the total temporal isolation interval in Experiment 1 using FR scoring (Panel A) and SR scoring (Panel B), in Experiment 2 using FR scoring (Panel C) and SR scoring (Panel D), in Experiment 3 using FR scoring (Panel E) and SR scoring (Panel F).

to ensure the experimental conditions were as similar as possible across all three participant groups.

Participants were instructed to recall as many words as they could on the paper response sheet: in any order for the IFR group; in the same serial position, but in a forwards output direction only for the ISR group; and in the same serial position, but in any output order for the ISR-free group. Trials had no maximum recall period; rather, participants ended recall when they felt they had remembered all the words they could.

Results

Two types of scoring were used: an item was scored as correct if it was recalled at any output position in the correct trial (*FR scoring*), or in the correct serial position (*SR scoring*). 7.6% of the responses were errors and were discarded.

The effect of total temporal isolation interval on the proportion of correctly recalled words

Fig. 1 shows the proportion of words recalled for the three tasks as a

Table 3
Summary of the ANOVA tables from analyses examining the effect of total temporal isolation interval on the proportion of correctly recalled words from Experiments 1, 2 and 3. The total temporal isolation interval refers to the sum of the intervals before and after a target word.

Experiment 1, 2 and 3	*df*	*MSE*	*F*	η_p^2	*p*
Proportion of words recalled as a function of total temporal isolation interval					
Experiment 1 (FR scoring)					
Task	2, 102	.116	3.70	.068	.028
Total temporal isolation interval	6.01, 613.1	.011	5.33	.050	< .001
Task × total temporal isolation interval	12.02, 613.1	.011	1.21	.023	.269
Experiment 1 (SR scoring)					
Task	2, 102	.089	78.6	.607	< .001
Total temporal isolation interval	5.51, 532.2	.008	3.93	.037	.001
Task × total temporal isolation interval	11.02, 562.2	.008	2.29	.043	.009
Experiment 2 (FR scoring)					
Task	2, 60	.086	4.78	.137	.012
Total temporal isolation interval	4.92, 295.2	.060	1.94	.031	.090
Task × total temporal isolation interval	9.84, 295.2	.060	1.21	.039	.285
Experiment 2 (SR scoring)					
Task	2, 60	.020	21.8	.420	< .001
Total temporal isolation interval	4.85, 291.2	.015	.675	.011	.638
Task × total temporal isolation interval	9.71, 291.2	.015	.897	.029	.534
Experiment 3 Digit-filled intervals (FR scoring)					
Task	1, 46	.058	.010	< .001	.920
Total temporal isolation interval	2, 92	.005	3.50	.071	.034
Task × total temporal isolation interval	2, 92	.005	1.14	.024	.326
Experiment 3 Digit-filled intervals (SR scoring)					
Task	1, 46	.040	108.4	.702	< .001
Total temporal isolation interval	2, 92	.004	8.96	.163	< .001
Task × total temporal isolation interval	2, 92	.004	2.19	.045	.117
Experiment 3 Unfilled temporal intervals (FR scoring)					
Task	1, 46	.031	6.39	.122	.015
Total temporal isolation interval	1.62, 74.6	.005	4.68	.092	.018
Task × total temporal isolation interval	1.62, 74.6	.005	.266	.006	.721
Experiment 3 Unfilled temporal intervals (SR scoring)					
Task	1, 46	.024	41.9	.477	< .001
Total temporal isolation interval	2, 92	.002	4.41	.087	.015
Task × total temporal isolation interval	2, 92	.002	2.15	.045	.123

function of total temporal isolation interval using both FR scoring (Fig. 1A) and SR scoring (Fig. 1B). Contrary to the classic TIE findings, there was not a systematic increase in recall with increased total temporal isolation intervals in any task with either scoring system. Table 3 summarises the findings of a pair of 3 (task: IFR, ISR-free, or ISR) × 10 (total temporal isolation interval (in seconds): 0.00, 0.55, 1.10, 1.65, 2.20, 3.30, 3.85, 4.40, 5.50, and 7.70) mixed ANOVAs conducted on the proportion of words correctly recalled as a function of total temporal isolation interval using first FR scoring and then SR scoring.

Using FR scoring, the linear contrast for the main effect of total temporal isolation interval was significant and negative, F (1, 102) = 7.25, MSE = .012, η_p^2 = .066, p = .008, with greater recall for *smaller* total temporal isolation intervals. The mean proportion of words recalled in IFR was significantly greater than ISR, but neither were significantly different from ISR-free. There was no interaction between task and total temporal isolation interval using FR scoring.

Using SR scoring, the linear contrast for the main effect of total temporal isolation intervals was significant and also negative, F (1, 102) = 7.16, MSE = .007, η_p^2 = .066, p = .009, with greater recall again for *smaller* total temporal isolation intervals. Correct recall using SR scoring was significantly different for all tasks (IFR < ISR < ISR-free). An examination of the interaction between task and pre-item interval using SR scoring revealed that as the total temporal isolation intervals increased, performance was unaffected in IFR, but there was a decrease in the performance of ISR and a very slight decrease in the performance of ISR-free.

Overall, crucially there was no systematic increase in recall with increasing total temporal isolation intervals in any task with either scoring system, and, if anything, increased recall with *smaller* total temporal isolation intervals.

Analysis of the serial position curves as a function of pre- and post-item interval

Fig. 2 shows the serial position curves for each of the three tasks as a function of pre-item and post-item interval using FR scoring. The findings of a pair of 3 (task: IFR, ISR-free, or ISR) × 4 (pre-item or post-item intervals: 0 digits, 1 digit, 3 digits, and 7 digits) × 7 (serial position: SPs 1–7) mixed ANOVAs conducted on the proportion of correctly recalled words using FR scoring are summarised in the upper rows of Table 4.

We consider first the effects of pre-item intervals shown in the left-hand panels of Fig. 2. The linear contrast for the main effect of pre-item interval was significant and positive, F (1, 102) = 56.3, MSE = .015, η_p^2 = .356, p < .001, with increased recall when there were *longer pre*-item intervals. The higher recall for longer pre-item intervals was significant for the recency serial positions; but there was also higher recall for a pre-item interval of 0 digits at SP1. There were significant primacy effects and extended recency effects, and lower recall for recency serial positions in ISR compared with IFR and ISR-free.

We consider next the effects of the post-item intervals shown in the right-hand panels of Fig. 2. The linear contrast for the main effect of post-item interval was significant and negative, F (1, 102) = 163.2, MSE = .017, η_p^2 = .615, p < .001, with increased recall when there were shorter post-item intervals. The higher recall for shorter post-item intervals was significant at the recency serial positions, but there was also higher recall for longer post-item intervals at SP1. There were

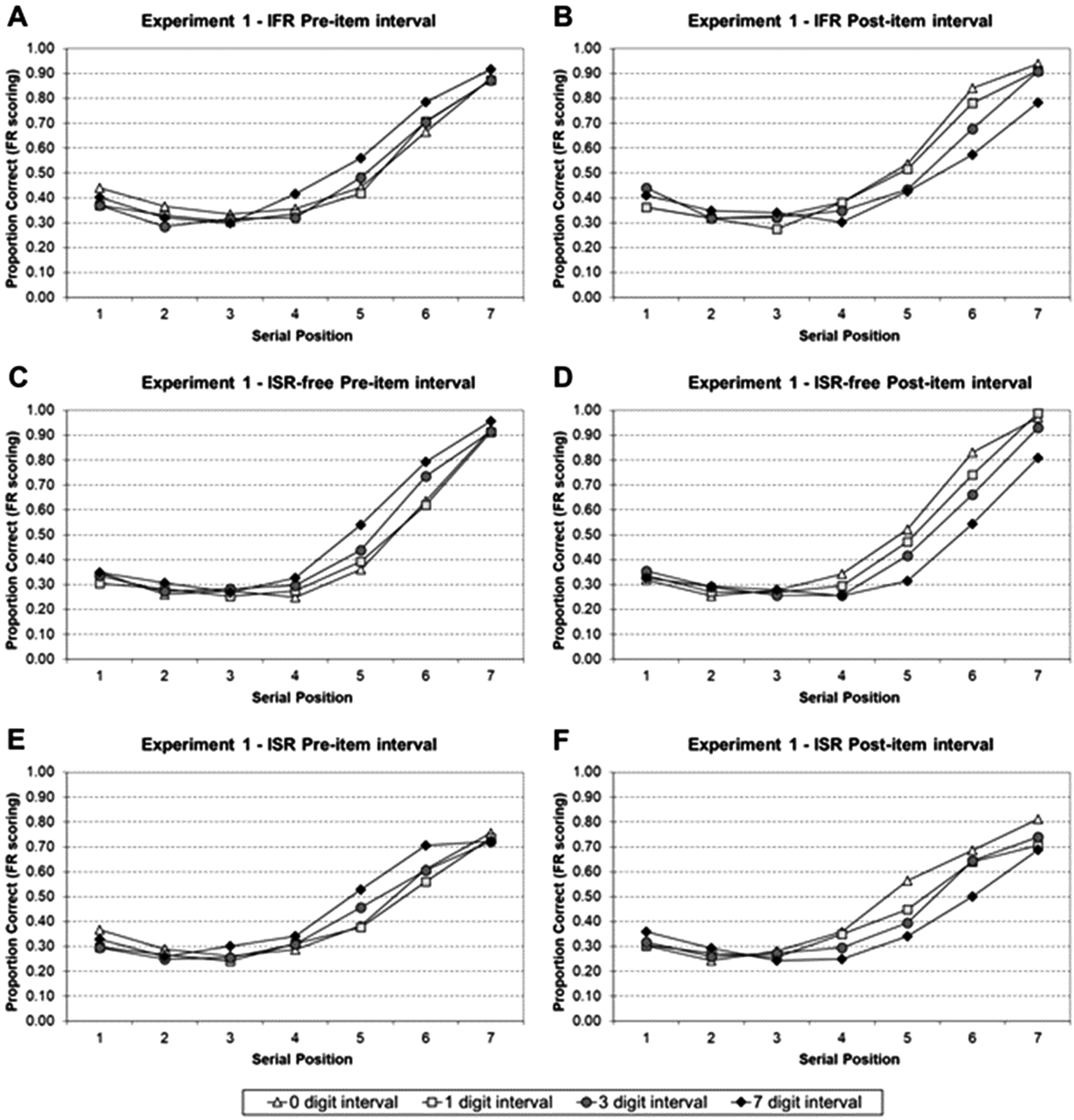

Fig. 2. Data from Experiment 1: Serial position curves for IFR, ISR-free, and ISR using FR scoring as a function of pre-item intervals in Panels A, C, and E respectively, and as a function of post-item intervals in Panels B, D, and F respectively.

again significant primacy effects and extended recency effects, with lower recall at recency serial positions in ISR, and heightened recall at SP7 in ISR-free. Finally, an examination of the 3-way interaction revealed a reduced effect of the post-item interval at SP5 in IFR compared to ISR and ISR-free, a reduced effect at SP6 in ISR compared to IFR and ISR-free, and reduced recency in ISR compared to IFR and ISR-free.

Fig. 3 shows the effect of pre-item and post-item intervals on the serial position curves for the serial recall tasks using SR scoring. A further pair of 2 (task: ISR-free or ISR) × 4 (pre-item or post-item interval: 0 digits, 1 digit, 3 digits, and 7 digits) × 7 (serial position: SPs 1–7) mixed ANOVAs on the proportion of words recalled SR scoring are summarised in the lower rows of Table 4. There were significant primacy effects and extended recency effects, and there was greater recency in ISR-free. Recall in ISR-free was significantly greater than in ISR for all but the shortest pre-item intervals and for all but the longest post-item intervals.

The main findings with SR scoring were broadly similar to those reported above with FR scoring. The linear contrast for the main effect of pre-item interval was again significant and positive, $F(1, 68) = 83.8$, $MSE = .008$, $\eta_p^2 = .552$, $p < .001$, with increased recall with *longer pre*-item intervals. The linear contrast for the main effect of post-item intervals was again significant and negative, $F(1, 68) = 219.8$, $MSE = .009$, $\eta_p^2 = .764$, $p < .001$, with increased recall for words followed by *shorter post*-item intervals. Both the pre-item advantages for longer intervals and the post-item advantages for shorter intervals were greatest toward the end of the list; and the effects somewhat reversed on the recall of the first item.

Overall, it is clear that there are broadly similar patterns of TIEs across IFR, ISR-free and ISR using FR scoring. Recall increases with both

Table 4
Summary of the ANOVA tables from analyses conducted on the serial position curves as a function of temporal isolation interval from Experiment 1.

Experiment 1	*df*	*MSE*	*F*	η_p^2	*p*
SPC as a function of pre-item interval (FR scoring)					
Task	2, 102	.325	4.10	.074	.019
Pre-item interval	2.78, 283.8	.012	44.0	.302	< .001
SP	2.07, 211.0	.118	500.2	.831	< .001
Task × pre-item interval	5.57, 283.8	.012	3.27	.060	.005
Task × SP	4.14, 211.0	.118	4.85	.087	.001
Pre-item interval × SP	18, 1836	.011	9.28	.083	< .001
Task × pre-item interval × SP	29.8, 1519.2	.014	1.04	.020	.404
SPC as a function of post-item interval (FR scoring)					
Task	2, 102	.328	4.03	.073	.021
Post-item interval	2.78, 282.4	.014	75.2	.424	< .001
SP	2.12, 215.9	.116	498.7	.830	< .001
Task × post-item interval	5.54, 282.4	.014	1.32	.025	.251
Task × SP	4.23, 215.9	.116	4.71	.084	.001
Post-item interval × SP	14.2, 1452.5	.014	22.6	.182	< .001
Task × post-item interval × SP	28.5, 1452.5	.014	2.13	.040	.001
SPC as a function of pre-item interval (SR scoring)					
Task	1, 68	.318	9.27	.120	.003
Pre-item interval	3, 204	.008	39.6	.368	< .001
SP	1.75, 118.6	.158	254.1	.789	< .001
Task × pre-item interval	3, 204	.008	6.38	.086	< .001
Task × SP	1.75, 118.6	.158	22.2	.246	< .001
Pre-item interval × SP	12.8, 868.6	.013	14.2	.173	< .001
Task × pre-item interval × SP	12.8, 868.6	.013	1.94	.028	.024
SPC as a function of post-item interval (SR scoring)					
Task	1, 68	.324	8.87	.115	.004
Post-item interval	3, 204	.009	68.7	.503	< .001
SP	1.81, 123.3	.153	251.5	.787	< .001
Task × post-item interval	3, 204	.009	5.28	.072	.002
Task × SP	1.81, 123.3	.153	21.7	.242	< .001
Post-item interval × SP	18, 1224	.010	33.6	.331	< .001
Task × post-item interval × SP	13.3, 905.8	.013	2.18	.031	.008

FR scoring and SR scoring for words at the end of the list that are preceded with *longer* pre-item intervals and followed by *shorter* post-item intervals. There is a minor reversal of these effects in the recall of serial position 1: recall of the first list item tends to improve with shorter pre-item and longer post-item intervals.

The Probability of First Recall (PFR)

Table A1 (see Appendix A) shows the frequencies with which participants initiated their recalls with words from particular serial positions in Experiment 1. Participants followed instructions and initiated recall with SP1 in ISR more than any other serial position, but rarely initiated recall with the first item when they were free to initiate recall with any list item (as in IFR and ISR-free).

Table 5 summarises the findings of a 3 (task: IFR, ISR-free, or ISR) × 4 (pre-item interval: 0, 1, 3, and 7 digits) mixed ANOVA conducted on the probability of initiating recall with one of the last 4 items. The probability of initiating recall with one of the last 4 items was significantly different for all tasks (ISR < IFR < ISR-free). The linear contrast for the main effect of pre-item interval was significant and positive, F (1, 102) = 76.1, MSE = .014, η_p^2 = .427, p < .001, with *longer pre*-item intervals resulting in increased probability of initiating recall with one of the last 4 items. An examination of the interaction between task and pre-item interval revealed that the tendency to initiate recall with one of the last 4 words with increasing pre-item interval was greater for IFR and ISR than for ISR-free.

Table 5 also summarises the findings of a corresponding 3 × 4 mixed ANOVA analysis examined the tendency to initiate recall with the first list item (SP1). The probability of initiating recall with the first item was significantly different for all tasks (ISR-free < IFR < ISR). The linear contrast for the main effect of pre-item interval was significant and negative, F (1, 102) = 62.3, MSE = .006, η_p^2 = .379, p < .001, with *smaller* pre-item intervals resulting in increased probability of initiating recall with the first item (for IFR and ISR but not for ISR-free).

Thus, increasing the pre-item interval increased the PFR for recency items (Last 4) in all three tasks (albeit to a lesser extent in ISR-free), but increasing the pre-item interval either *decreased* the PFR for the first item (SP1) in IFR and ISR or did not affect the PFR for the first item (SP1) in ISR-free.

The effect of pre-item interval on Lag + 1 transitions

For each response (other than the first) on a trial, the *Lag* (Kahana, 1996) was calculated by subtracting the serial position of one response, *n,* from the serial position of the next response, *n + 1*. A Lag of + 1 refers to a successive pair of responses in which the pair of words are recalled in exactly the same order as that in which they had been presented (e.g., a word presented at serial position 4 was recalled immediately after the word that had been presented at serial position 3). For each participant and each trial we counted the number of Lag + 1 transitions that were observed as well as the opportunities to make Lag + 1 transitions. In calculating the Lag + 1 opportunities, we assumed that participants would not recall the same word twice, nor could they make a Lag + 1 opportunity immediately after the last list item (SP7) or an error. For each participant, we divided the observed number of Lag + 1 transitions by the Lag + 1 opportunities in order to calculate the Conditionalized Response Probabilities (CRP) of Lag + 1 transitions (see Kahana, 1996).

The upper values in Table 6 show how the CRP values of Lag + 1 transitions in Experiment 1 varied as a function of the task, the serial position of the second response, and the pre-item interval (the inter-stimulus interval between the pair of successive items). As Table 6 shows, smaller pre-item intervals facilitated transitions between successive items, and this was more salient when participants were free to output the words in any order that they wished (i.e., IFR and ISR-free).

Table 7 summarises the findings of a 3 (task: IFR, ISR-free, or ISR) × 4 (pre-item interval: 0, 1, 3, and 7 digits) mixed ANOVA which examined the proportion of Lag + 1 transitions performed. The proportion of Lag + 1 transitions performed in IFR was significantly lower than ISR and ISR-free, which did not differ from each other. The linear contrast for the main effect of pre-item interval was significant and negative, F (1, 101) = 195.6, MSE = .019, η_p^2 = .660, p < .001, with *smaller* pre-item intervals resulting in an increased proportion of Lag + 1 transitions.

Thus, the tendency to transition in a forward order was greater for ISR and ISR-free than for IFR, and critically, the tendency to transition in a forward order increased with *decreasing* pre-item intervals.

Discussion

Overall, the results of Experiment 1 did not show the typical overall effect of temporal isolation. According to the temporal distinctiveness accounts (e.g. Baddeley, 1976; Bjork & Whitten, 1974; Brown et al., 2007; Crowder, 1976), longer pre-item intervals and longer post-item intervals should both positively enhance recall. By contrast, we found that recall performance did not increase systematically with total-temporal isolation interval, and we observed this pattern in all three tasks.

Although we failed to find increased recall with increasing total temporal isolation, we nevertheless observed both *positive* and *negative* effects of increasing temporal isolation intervals on recall. In the second half of the list, recall increased with *longer pre*-item intervals, and recall also increased with *shorter post*-item intervals, and similar patterns were observed for all three tasks (and both scoring systems). Moreover, participants were more likely to initiate recall with an item in the second half of the list if it was preceded with a *longer pre*-item interval. Furthermore, we found that the proportion of Lag + 1 transitions (i.e., transitions between successively presented items) increased when the successive items were separated by a *smaller* inter-stimulus interval. Thus, one reason why we found no overall recall advantage in the total temporal isolation interval was because there were both recall

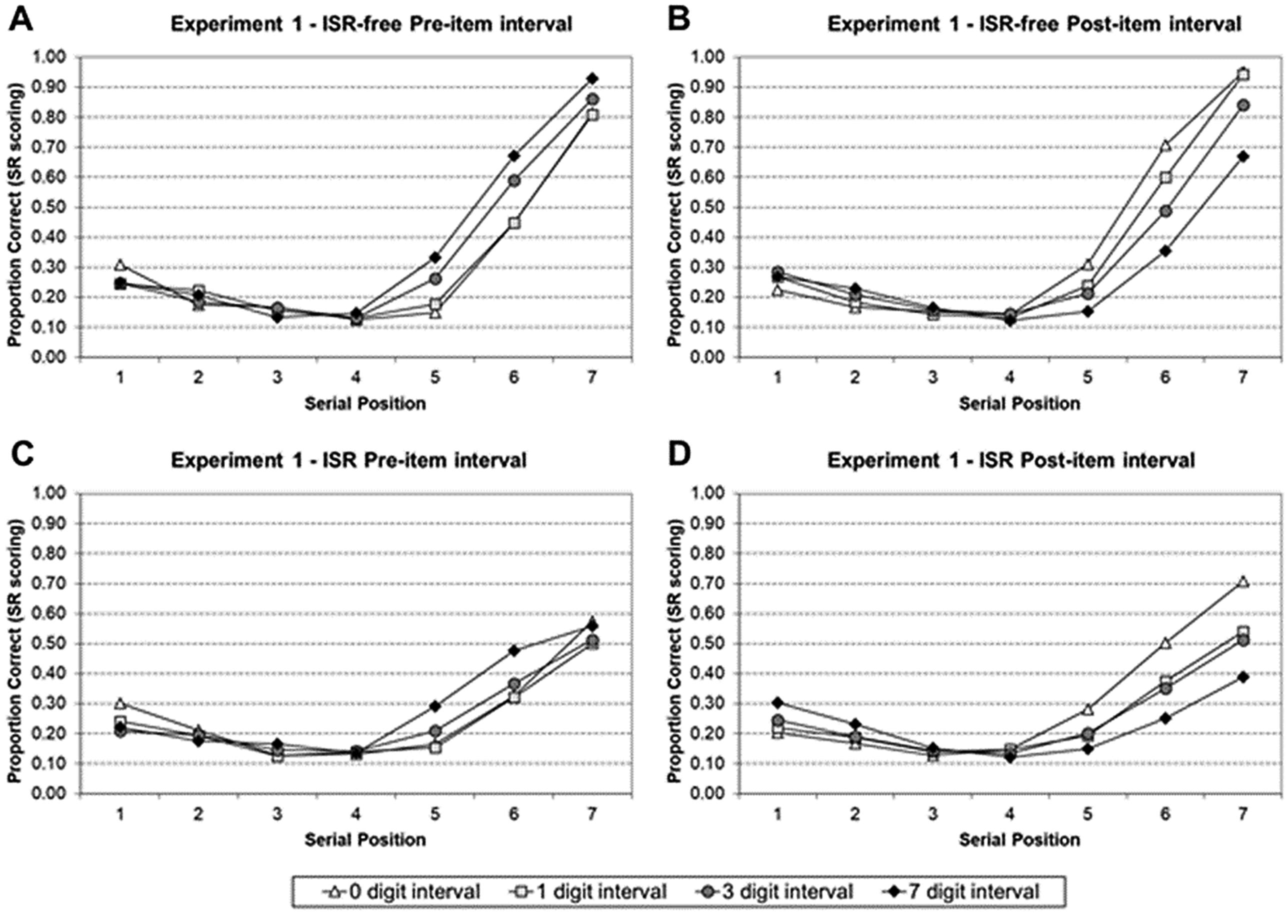

Fig. 3. Data from Experiment 1: Serial position curves for ISR-free and ISR using SR scoring as a function of pre-item intervals in Panels A and C respectively, and as a function of post-item intervals in Panels B and D respectively.

Table 5
Summary of the ANOVA tables from analyses conducted on the probability of first recall (PFR) data from Experiments 1, 2 and 3.

Experiment 1, 2 and 3	*df*	*MSE*	*F*	η_p^2	*p*
PFR of SP = 1 as a function of pre-item interval					
Experiment 1					
Task	2, 102	.066	40.4	.442	< .001
Pre-item interval	2.45, 249.9	.007	23.7	.189	< .001
Task × pre-item interval	4.90, 249.9	.007	4.70	.084	< .001
PFR of Last4 as a function of pre-item interval					
Experiment 1					
Task	2, 102	.095	86.3	.629	< .001
Pre-item interval	2.49, 253.4	.013	36.3	.262	< .001
Task × pre-item interval	4.97, 253.4	.013	3.63	.067	.003
Experiment 2					
Task	2, 64	.002	129.3	.802	< .001
Pre-item interval	2.23, 142.6	.004	10.5	.141	< .001
Task × pre-item interval	4.46, 142.6	.004	2.44	.071	.044
Experiment 3 Digit-filled intervals					
Task	1, 42	.010	351.2	.893	< .001
Pre-item interval	1, 42	.008	39.4	.484	< .001
Task × pre-item interval	1, 42	.008	47.2	.529	< .001
Experiment 3 Unfilled temporal intervals					
Task	1, 38	.008	36.8	.492	< .001
Pre-item interval	1, 38	.008	42.4	.527	< .001
Task × pre-item interval	1, 38	.008	36.8	.492	< .001

advantages for *longer pre*-item intervals (such as when initiating recall) but also recall advantages for *smaller* pre-item intervals (such as when continuing recalls with a Lag + 1 transition).

We interpret these patterns of results within a grouping explanation (cf. Farrell et al., 2011; Farrell, 2012; Spurgeon, Ward, Matthews, & Farrell, 2015). Our hypothesis is that participants may voluntarily segment a 7-item list into two (or more) subgroups, but the position of the group boundaries may be affected by the inter-stimulus intervals between the list items. Whereas the start of the first group is always the first word, the start of a second group may be encouraged (1) when the first group already contains a few items, (2) when there is a large pause immediately before the start of a putative second group, and (3) when there is a minimal pause immediately after the start of a putative second group. A large pause before the start of a new group may encourage the conclusion of one group and the anticipation of the next, and a minimal pause after the start of a new group may help participants treat successive items as a pair of items within a new group, resulting in increased Lag + 1 transitions within a group. If one further assumes that there is privileged access to the first item of the most recent group (Farrell, 2012), and to a lesser extent, privileged access to the first item of earlier groups (Spurgeon et al., 2015), and that participants can make use of bottom-up mechanisms to segment irregularly grouped sequences in immediate recall tasks (Hartley, Hurlstone, & Hitch, 2016), then a grouping explanation can help explain this complex pattern of pre-item and post-item intervals at later serial positions.

Table 6
The Conditionalized Response Probabilities (CRPs) of lag + 1 responses as a function of task and pre-item interval. The first sub-table reflects the data from Experiment 1, the second sub-table reflects the data from Experiment 2, the third sub-table reflects the data from Experiment 3 (digit-filled intervals) and the final sub-table reflects the data from Experiment 3 (unfilled temporal intervals).

Experiment	Task	Pre-item interval (digits)			
		0	1	3	7
Experiment 1	IFR	.654	.521	.472	.354
	ISR-free	.731	.620	.540	.460
	ISR	.703	.567	.557	.476
		Pre-item interval (digits)			
		0	1–3	4–6	7
Experiment 2	IFR	.413	.300	.255	.193
	ISR-free	.320	.317	.319	.273
	ISR	.509	.383	.325	.350
		Pre-item interval (digits)			
			1		7
Experiment 3 (digit-filled intervals)	IFR		.737		.621
	ISR		.859		.821
		Pre-item interval (time, ms)			
			100		1000
Experiment 3 (unfilled temporal intervals)	IFR		.699		.646
	ISR		.725		.706

Table 7
Summary of the ANOVA tables from analyses conducted on the effect of pre-item interval on lag + 1 transitions from Experiments 1, 2 and 3.

Experiment 1, 2 and 3	*df*	*MSE*	*F*	η_p^2	*p*
Lag + 1 transitions as a function of pre-item interval					
Experiment 1					
Task	2, 101	.045	7.00	.122	.001
Pre-item interval	3, 303	.017	73.8	.422	< .001
Task × pre-item interval	6, 303	.017	.937	.018	.468
Experiment 2					
Task	2, 69	.074	3.81	.099	.027
Pre-item interval	2.25, 155.1	.044	8.25	.107	< .001
Task × pre-item interval	4.50, 155.1	.044	1.62	.045	. 164
Experiment 3 Digit-filled intervals					
Task	1, 46	.021	29.3	.389	< .001
Pre-item interval	1, 46	.009	15.8	.255	< .001
Task × pre-item interval	1, 46	.009	4.07	.081	.049
Experiment 3 Unfilled temporal intervals					
Task	1, 46	.015	2.95	.060	.093
Pre-item interval	1, 46	.005	6.19	.119	.017
Task × pre-item interval	1, 46	.005	1.45	.031	.234

We note that grouping has previously been associated with TIEs, and there are some effects of grouping on both tasks. A rare observation of a TIE in ISR was shown by Farrell (2008) who found that the greatest effects of temporal isolation in ISR were using grouped lists. Grouping instructions also interacted with inter-stimulus interval between the group boundary in the ISR studies of Farrell et al. (2011). Moreover, grouping has been often observed in ISR (e.g., Farrell & Lewandowsky, 2004; Frankish, 1985; Hartley et al., 2016; Henson, 1999; Hitch, Burgess, Towse, & Culpin, 1996; Maybery, Parmentier, & Jones, 2002; Ryan, 1969), and grouping has been shown to affect at least the distribution of initial recalls in IFR (Spurgeon et al., 2015).

Finally, the data from Experiment 1 suggest that there are more similarities than differences between the effects of temporal isolation on IFR and ISR (and ISR-free) when the tasks are compared at shorter list lengths. Rather than an integrated account of IFR and ISR having to explain the different patterns of findings with different tasks, our data suggest that very similar explanations might be able to underpin both tasks when short lists are used.

Experiment 2

In Experiment 2, we sought to re-examine the magnitude and extent of TIEs using a much longer list length (17 words), that is more typical of that standardly used in IFR. Of interest was whether the significant TIE observed by Brown et al. (2006) using 17-word lists was obtained because of the task that was used (perhaps owing to participants' freedom to control their output order, Lewandowsky et al., 2008) or whether the significant TIE observed by Brown et al. (2006) was obtained because of the far longer list length that was used.

At longer list lengths, there is more opportunity for participants to segment the list into multiple subgroups, and if TIEs are exaggerated at group boundaries then it is possible that TIEs will be observed in both IFR and ISR, because prior research suggests that both tasks are sensitive to initial output order effects following grouping manipulations (Spurgeon et al., 2015). Therefore, it is possible that TIEs may be found even in ISR and ISR-free when the list length far exceeds span; items with greater temporal isolation may become more salient at longer list lengths.

Alternatively, TIEs may be observed primarily when participants are free to recall in any order (Lewandowsky et al., 2008), and so may be observed only in IFR (Brown et al., 2006) and not ISR. By incorporating a third group, performing ISR-free, we would be able to determine whether TIEs emerge when freedom of output order was allowed (in which case, we should see similar effects in IFR and ISR-free), or whether TIEs are reduced or eliminated in tasks where participants must assign stimuli to their correct serial positions (in which case, we should see similar effects in ISR and ISR-free).

In Experiment 2, there were three groups of participants examining TIEs in 17-word lists. One group replicated the method and list length of Brown et al. (2006, Experiment 2) that had been used to show TIEs in IFR, and two other groups used identical methodologies and were run to extend that study to examine TIEs at long list lengths with the ISR and ISR-free tasks.

Method

Participants

A total of 72 students from University of Essex took part in this experiment in exchange for course credit.

Materials and apparatus

These were identical to those used in Experiment 1 except a subset of 374 words were randomly selected for each participant from the Toronto Word Pool (Friendly et al., 1982).

Design

The design was identical to that used in Experiment 1, except the inter-stimulus intervals contained 0, 1, 2, 3, 4, 5, 6 and 7 digits (leading to pre-item and post-item intervals of 0–7 digits and total temporal isolation intervals of between 0 and 7 s) and 17-word lists were used (leading to SPs between 1 and 17).

Procedure

There were four changes to the procedure that was used in Experiment 1. First, participants received two practice lists of 17 words each followed by a further 20 experimental lists of 17 words, separated into two blocks. Second, we followed the procedure of Brown et al.

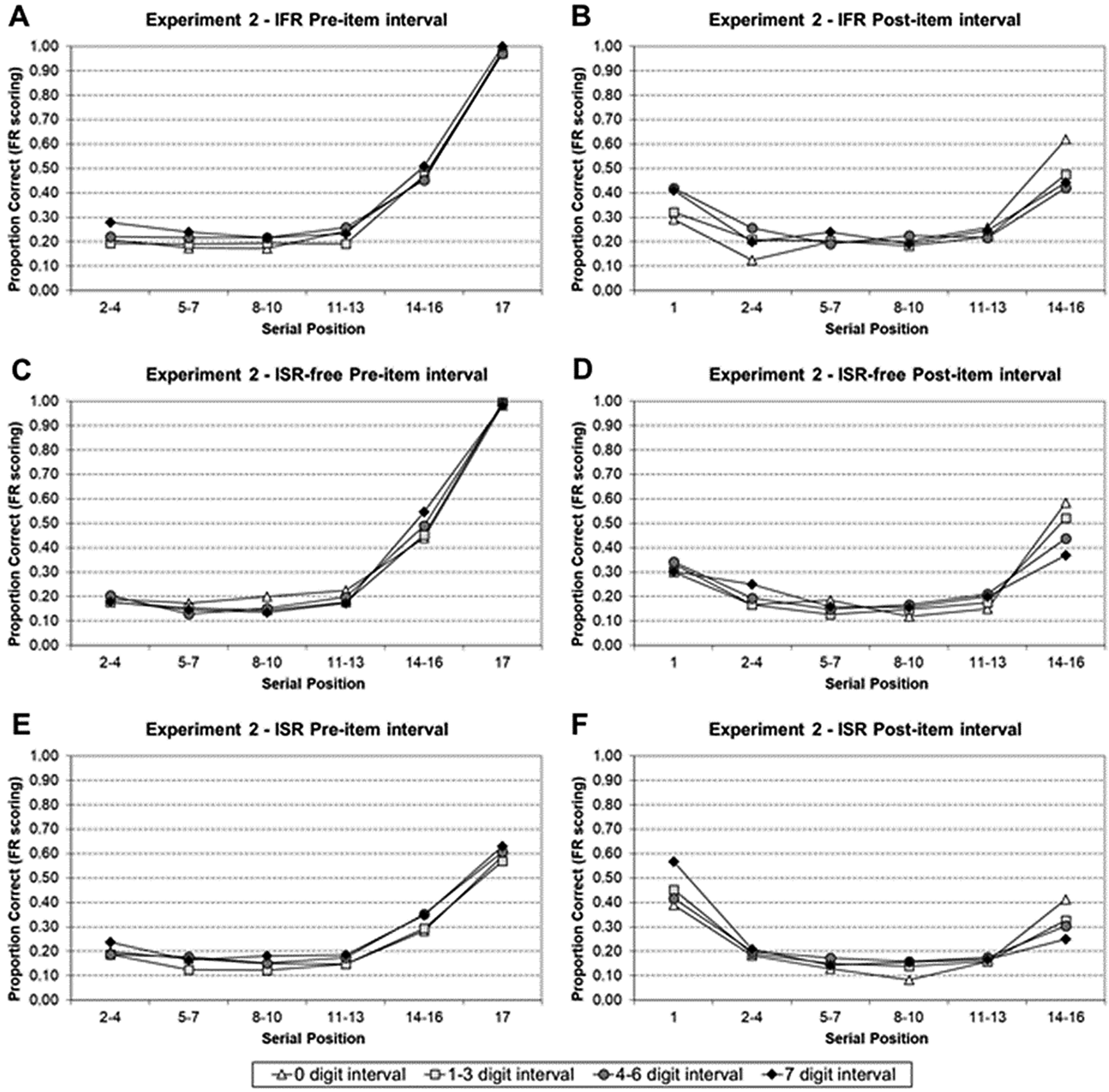

Fig. 4. Data from Experiment 2: Serial position curves for IFR, ISR-free, and ISR using FR scoring as a function of pre-item intervals in Panels A, C, and E respectively, and as a function of post-item intervals in Panels B, D, and F respectively.

(2006), where there was a fixation cross followed by no pre-item interval before the first word and a fixed post-item interval of 150 ms after the last word, and the 16 inter-stimulus intervals were randomly filled with exactly two instances each of 0, 1, 2, 3, 4, 5, 6 and 7 digits across the inter-stimulus intervals of each trial. Third, the presentation rate of the words was unchanged from Experiment 1, but the digits were presented at a rate of 1 digit every 500 ms (350 ms, 150 ms off).

Results

A total of 6.9% of the responses were errors and were discarded.

The effect of total temporal isolation interval on the proportion of correctly recalled words

Fig. 1 shows the proportion of words recalled for the three tasks as a function of total temporal isolation interval using both FR scoring (Fig. 1C) and SR scoring (Fig. 1D). For these analyses, we excluded data from SP1 and SP17, because using the method of Brown et al. (2006), there were no digits presented before the first and after the last word.

Table 3 summarises the findings of a pair of 3 (task: IFR, ISR-free, or ISR) × 15 (total temporal isolation interval (in seconds): 0.00, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, and 7.0) mixed ANOVAs conducted on the proportion of words correctly recalled as a function of total temporal isolation interval using FR and SR scoring. Regardless of the scoring method, there was no significant main effect of total temporal isolation interval, nor did it significantly interact with task. However, recall was greater in IFR than ISR using FR scoring; but recall was greater in ISR and ISR-free than IFR using SR scoring.

Overall, it is clear that there was no overall effect of the total temporal isolation interval on the proportion of correctly recalled words, regardless of the type of task that was performed or the scoring system that was used.

Table 8
Summary of the ANOVA tables from analyses conducted on the serial position curves as a function of temporal isolation interval from Experiment 2.

Experiment 2	*df*	*MSE*	*F*	η_p^2	*p*
SPC as a function of pre-item interval (FR scoring)					
Task	2, 62	.098	23.6	.432	< .001
Pre-item interval	2.53, 156.9	.021	4.00	.061	.013
SP	3.21, 199.2	.053	552.6	.899	< .001
Task × pre-item interval	5.06, 156.9	.021	1.23	.039	.296
Task × SP	6.42, 199.2	.053	22.2	.417	< .001
Pre-item interval × SP	9.76, 604.9	.027	1.01	.016	.433
Task × pre-item interval × SP	19.5, 604.9	.027	.718	.023	.806
SPC as a function of post-item interval (FR scoring)					
Task	2, 57	.122	.275	.010	.760
Post-item interval	2.45, 139.5	.029	.556	.010	.610
SP	2.92, 166.4	.065	85.0	.599	< .001
Task × post-item interval	4.90, 139.5	.029	.174	.006	.970
Task × SP	5.84, 166.4	.065	7.46	.207	< .001
Post-item interval × SP	5.69, 324.4	.070	3.90	.064	.001
Task × post-item interval × SP	11.4, 324.4	.070	1.06	.036	.395
SPC as a function of pre-item interval (SR scoring)					
Task	1, 41	.107	26.7	.394	< .001
Pre-item interval	2.53, 103.6	.014	3.09	.070	.038
SP	1.62, 66.48	.139	240.1	.854	< .001
Task × pre-item interval	2.53, 103.6	.014	.333	.008	.767
Task × SP	1.62, 66.5	.139	36.13	.468	< .001
Pre-item interval × SP	4.91, 201.2	.042	3.05	.069	.012
Task × pre-item interval × SP	4.91, 201.2	.042	.592	.014	.703
SPC as a function of post-item interval (SR scoring)					
Task	1, 40	.087	.602	.015	.442
Post-item interval	2.59, 103.6	.020	.311	.008	.788
SP	2.01, 80.2	.090	83.4	.676	< .001
Task × post-item interval	2.59, 103.6	.020	1.56	.038	.208
Task × SP	2.01, 80.2	.090	13.6	.254	< .001
Post-item interval × SP	3.87, 154.9	.065	4.10	.093	.004
Task × post-item interval × SP	3.87, 154.9	.065	1.03	.025	.390

Analysis of the serial position curves as a function of pre- and post-item interval

Fig. 4 shows the serial position curves for each of the three tasks as a function of pre-item and post-item interval using FR scoring. We condensed the serial positions across 7 categories (pre-item: SPs 2–4, SPs 5–7, SPs 8–10, SPs 11–13, SPs 14–16, and SP17; post-item: SP1, SPs 2–4, SPs 5–7, SPs 8–10, SPs 11–13, and SPs 14–16) and the pre-item and post-item intervals over 4 different ranges (0 digits, 1–3 digits, 4–6 digits and 7 digits).

We first consider the effects of pre-item intervals, shown in the left-hand panels of Fig. 4. Table 8 summarises the findings of a 3 (task: IFR, ISR-free, or ISR) × 4 (pre-item interval: 0 digits, 1–3 digits, 4–6 digits and 7 digits) × 6 (serial position: SPs 2–4, SPs 5–7, SPs 8–10, SPs 11–13, SPs 14–16 and SP17) mixed ANOVA conducted on the proportion of correctly recalled words using FR scoring. Since there was no pre-item interval for the first item, SP1 was excluded from this and subsequent analyses of pre-item intervals.

There was a significant main effect of pre-item interval, which did not interact with any other variable. There was a significant quadratic contrast, $F\,(1,\,62) = 4.84$, $MSE = .019$, $\eta_p^2 = .072$, $p = .032$, indicating that recall was greatest for the longest pre-item intervals (7 digits and 4–6 digits), but recall with a pre-item interval of 0 digits was greater than with a pre-item interval of 1–3 digits. The mean proportion of words recalled in ISR was significantly lower than IFR and ISR-free, which did not differ from each other. There were significant extended recency effects, which were reduced in ISR compared with IFR and ISR-free.

We consider next the effects of the post-item intervals shown in the right-hand panels of Fig. 4. Table 8 also summarises the findings of a 3 (task: IFR, ISR-free, or ISR) × 4 (post-item interval: 0 digits, 1–3 digits, 4–6 digits and 7 digits) × 6 (serial position: SP1, SPs 2–4, SPs 5–7, SPs 8–10, SPs 11–13, and SPs 14–16) mixed ANOVA conducted on the proportion of correctly recalled words using FR scoring. Since there were no digits after the last item, SP17 was excluded from this and subsequent post-item interval analyses.

Although there was not an overall main effect of post-item interval, there was a significant interaction between post-item interval and serial position. There was a recall advantage for shorter post-item intervals at recency positions (SPs 14–16), but a recall advantage for longer post-item intervals at SP1. The post-item interval did not interact with task or any other factor. There were again significant primacy effects and extended recency effects, and there was greater primacy and reduced recency in ISR.

Fig. 5 shows the serial position curves for the two serial recall tasks as a function of pre-item and post-item interval using SR scoring and the corresponding pair of ANOVAs using SR scoring are summarised in Table 8. We condensed the serial positions across 7 intervals (pre-item: SPs 2–4, SPs 5–7, SPs 8–10, SPs 11–13, SPs 14–16, and SP17; post-item: SP1, SPs 2–4, SPs 5–7, SPs 8–10, SPs 11–13, and SPs 14–16) and the pre-item and post-item intervals over 4 different ranges (0 digits, 1–3 digits, 4–6 digits and 7 digits).

In the analyses of the pre-item interval with SR scoring, there was a significant main effect of pre-item interval and a significant interaction between pre-item interval and serial position. There was an overall recall advantage for a longer pre-item interval (especially at SPs 2–4 and SPs 14–16), but recall with a 0 digit pre-item interval was greater than other pre-item intervals at SP17. There were significant recency effects, but significantly lower recall for the recency serial positions in ISR compared to ISR-free.

In the final analysis, we consider the effects of the post-item interval with SR scoring shown in the right-hand panels of Fig. 5. There was a recall advantage for shorter post-item intervals at the recency serial positions, and a recall advantage for longer post-item intervals at SP1. There were again significant primacy effects and extended recency effects, with greater primacy and reduced recency in the ISR task relative to the ISR-free task.

Overall, it is clear that there are quite complex patterns of TIEs that are relatively stable across the three tasks. In general, there are recall advantages for *longer pre*-item intervals and *shorter* post-item intervals at the end of the list. However, there is evidence that a pre-item interval of 0-digits is sometimes superior to pre-item interval of 1–3 digits, especially at the very last SP (SP17).

The Probability of First Recall (PFR)

Table A2 shows the frequencies with which participants initiated their recalls with words from particular serial positions in Experiment 2. Participants followed instructions and initiated recall with SP1 in ISR on just under half of the trials (203/480), but rarely initiated recall with the first item when they were free to initiate recall with any list item (as in IFR and ISR-free).

Table 5 summarises the findings of a 3 (task: IFR, ISR-free, or ISR) × 4 (pre-item interval: 0, 1–3, 4–6, and 7 digits) mixed ANOVA conducted on the probability of initiating recall with one of the last 4 items. The words presented in SP1 were excluded from the analyses since they were always preceded with a pre-item interval of 0 digits. The probability of initiating recall with one of the last 4 items was significantly lower in ISR than in IFR or ISR-free, which did not differ from each other. The linear contrast for the main effect of pre-item interval was significant and positive, $F\,(1,\,64) = 18.5$, $MSE = .004$, $\eta_p^2 = .224$, $p < .001$, with *longer* pre-item intervals resulting in increased probability of initiating recall with one of the last 4 items. An examination of the interaction between task and pre-item interval revealed that the interaction was primarily driven by the IFR data, where there was a stronger linear increase in the probability of initiating recall with one of the last 4 items as pre-item interval increased. In ISR, participants only initiated recall with one of the last 4 items on 14% of trials and in ISR-free, participants almost always initiate recall with

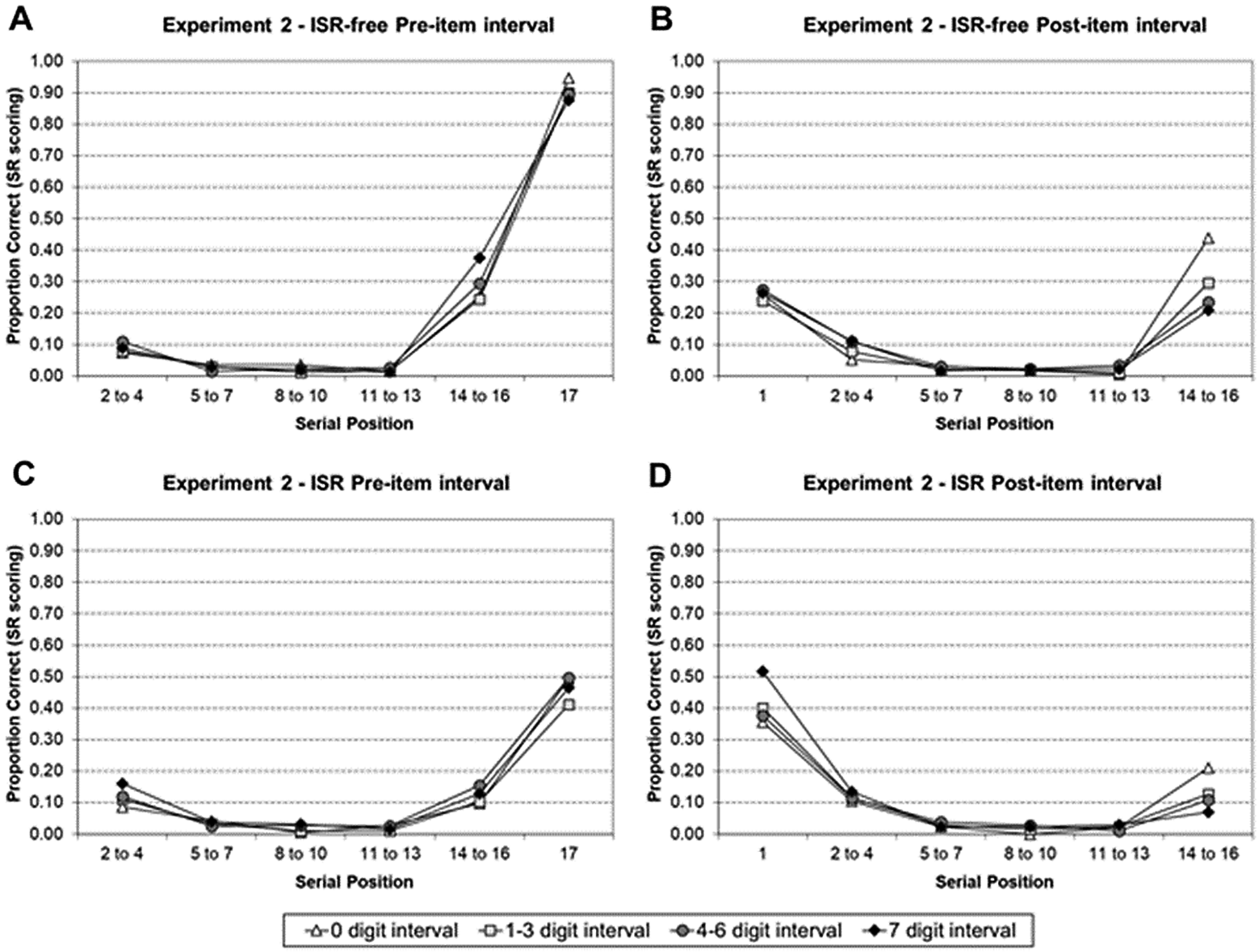

Fig. 5. Data from Experiment 2: Serial position curves for ISR-free and ISR using SR scoring as a function of pre-item intervals in Panels A and C respectively, and as a function of post-item intervals in Panels B and D respectively.

SP17 regardless of the pre-item interval.

Thus, participants initiated recall with one of the last 4 items significantly less often in ISR than in either IFR or ISR-free, and IFR showed a stronger linear increase as pre-item interval increased compared to the other tasks.

The effect of pre-item interval on Lag + 1 transitions

Table 6 shows how the CRP values of Lag + 1 transitions in Experiment 2 varied as a function of the task, the serial position of the second response, and the pre-item interval (the inter-stimulus interval between the pair of successive items). As Table 6 shows, smaller pre-item intervals facilitated transitions between successive items, and this is more salient when participants performed IFR.

Table 7 summarises the findings of a 3 (task: IFR, ISR-free, or ISR) × 4 (pre-item interval: 0, 1–3, 4–6, and 7 digits) mixed ANOVA conducted to examine the proportion of Lag + 1 transitions performed. The proportion of Lag + 1 transitions performed in IFR was significantly lower than ISR, but neither were significantly different from ISR-free. The linear contrast for the main effect of pre-item interval was significant and negative, F (1, 69) = 14.4, MSE = .053, η_p^2 = .172, p < .001, with *smaller* pre-item intervals resulting in an increased proportion of Lag + 1 transitions.

Thus, the tendency to transition in a forward order was lower for IFR, and, the tendency to transition in a forward order increased with *decreasing* pre-item intervals. Although there was non-significant interaction, we note that the transitions in ISR-free were relatively unaffected by pre-item interval.

Discussion

Experiment 2 was performed to investigate whether there would be a recall advantage with increased temporal isolation intervals for the longer lists (17 words) in IFR (as obtained by Brown et al., 2006), and whether we could extend this finding to the ISR and ISR-free tasks when we use near-identical methods across the three tasks. At first glance, and contrary to expectations, we found no positive effect of total temporal isolation interval for any of the three tasks (including IFR) using both FR scoring and SR scoring. The failure to find overall recall benefits of total temporal isolation interval mirrors similar findings from that Experiment 1, which used a shorter list length of 7 words.

In Experiment 2, we again found positive and negative effects of TIEs on recall. Consistent with Experiment 1, there were significant recall benefits for *longer pre*-item intervals (throughout the serial position curve, in the case of Experiment 2), and significantly greater recall for *shorter post*-item intervals later in the list. Task did not interact with the duration of the pre- and post-item interval in any of the serial position analyses. Moreover, there was an increased tendency to make Lag + 1 transitions with a pre-item interval of 0 digits (albeit that the effect appeared weak in ISR-free).

However, there were differences between the tasks in the effect of temporal isolation on the PFR in Experiment 2. The effect of pre-item interval on the PFR is most likely to be observed when participants can express a genuine choice as to which of multiple items they decide to recall first at test. In IFR, participants had a choice and they tended to initiate recall with one of the last 4 items and showed a heightened tendency to initiate recall with items preceded by a longer pre-item interval. However, participants' ability to express a choice in their PFR was greatly reduced with a 17-item list in the other two tasks when they had to allocate words to precise grid positions. In ISR, participants were required to initiate recall with SP1 and on only a small proportion of trials did they initiate recall with one of the last 4 items. In ISR-free, participants nominally had a choice but in practice they tended to initiate recall with the very last item (regardless of pre-item interval), perhaps reflecting their greater confidence in accurately allocating this word to its correct position in the grid.

Despite these differences in PFR, we can extend our grouping explanation from Experiment 1 to the longer list length of 17 words used in Experiment 2. It is possible that in all three tasks, participants try to segment a list of 17 words into multiple possible subgroups, of which only a few may be successfully accessed at recall. Starting a new group may be less likely if a putative first word in a group is preceded by a pre-item interval of 0 digits. Since Experiment 2 used a far longer list than was used in Experiment 1, the opportunities to start a new group (and for experiencing a positive recall benefit for a pre-item interval) are not limited to just the last few items but are instead extended to all but the very first few items. Following Spurgeon et al. (2015), we argue that there may be heightened access to the first item of a new subgroup even when it is not the first or the last. Following Farrell (2012) and Spurgeon et al. (2015), if there is privileged access to the first item of the most recent subgroup, then that item is most likely to be an item toward the end of the list, that is preceded by a large pre-item interval and a small post-item interval, a pattern of results consistent with the observed recall benefits.

Thus, the reason why there was not overall a systematic increase in recall with increased total temporal isolation interval appears again to be because there are both *positive* and *negative* effects of increased pre-item interval. Participants are more likely to recall items throughout the list with increased pre-item interval, and more likely to recall items at the end of the list with a reduced post-item interval. Moreover, participants are less likely to initiate recall with one of the Last 4 items with a pre-item interval of 0 digits, but more likely to make forward-ordered Lag + 1 transitions with a pre-item interval of 0 digits.

Experiment 3

Experiments 1 and 2 examined TIEs in IFR and ISR using a methodology adapted from the IFR studies of Brown et al. (2006) using shorter (Experiment 1) and longer (Experiment 2) list lengths. We found that the effects of temporal isolation were broadly similar across the two tasks: we found little or no evidence for a recall advantage with increased total temporal isolation on either task, but instead found more complex patterns of TIEs. To generalize, we found recall advantages for longer pre-item intervals and recall advantages for shorter post-item intervals.

However, one concern with these earlier experiments is that our serial position curves in ISR were atypical: we failed to find the extended primacy effects that are characteristically observed in ISR and our participants often failed to initiate recall with the first item. It is possible therefore that our atypical findings observed in Experiment 1 and 2 may reflect the methodological choices that we made, and that our TIE findings may not generalise to more conventional ISR methodologies.

In Experiments 1 and 2, temporal isolation was manipulated by varying the number of intervening digits that must be read aloud. The advantage of this method is that it greatly reduces the opportunity for rehearsal across long inter-stimulus intervals. However, there are also a number of disadvantages to this method. First, the use of intervening digits effectively transforms the IFR task into a continual distractor FR task and transforms the ISR task into a complex span task. Second, the words are not truly temporally isolated, but the method implicitly assumes that participants at retrieval can effectively discriminate the words independently from the digits. A third disadvantage of our method is that our written recall procedure using a response grid is also different from standard ISR, since it allows participants to initiate recall with later items more easily than is observed with oral recall, when "blank" or "pass" responses are typically required to signify omissions at output. Finally, our prior methodology varies the inter-stimulus intervals using 0–7 digits, but the difference between a 0-digit condition and a 1-digit condition may be qualitatively different from the difference between, say, a 2-digit and a 3-digit condition.

An alternative methodology that has been used to study TIEs in ISR is to use unfilled temporal intervals of unpredictable and differing durations between the list items. For example, Farrell et al. (2011, Experiment 2) presented sequences of 8 spoken digits. The temporal intervals before the first digit and after the last digit were fixed, but the seven inter-item intervals were separated by either 100 ms (short) or 1000 ms (long) unfilled temporal pauses. Using this method, Farrell et al. found extended primacy effects, and when participants were instructed to group the 8-item list into two mini-lists of 4-digits each, a recall advantage was observed that was attributable to a longer temporal interval between the fourth and fifth digits. As far as we are aware, this method has not been applied to IFR.

In Experiment 3, we examined TIEs in IFR and ISR using two different methodologies in an attempt to replicate our findings under methodologies that promoted greater extended primacy in the ISR task. First, on one half of the trials, we used the methodology with the digit-filled intervals that had been used in Experiment 1 (7 words) and Experiment 2 (17 words), but we reduced the list length to 5 words. Participants continued to write their responses, but in ISR had to write "blank" for any omissions. We predicted that the tendency to initiate recall with the first list item would increase at shorter list lengths (Ward et al., 2010), and so reducing the list length should increase the chance of demonstrating extended primacy effects. Specifically, we presented participants with lists of 5 words, the interval before the first item and after the last item was fixed and unfilled, leaving two inter-item intervals that were filled with 7 digits (long digit-filled interval) and two inter-item intervals that were filled with 1 digit (short digit-filled interval). Recall was written and in any order for IFR but in forward serial order for ISR, with participants indicating omissions in ISR by writing "blank".

On the other half of the trials, we adapted the procedure of Farrell et al. (2011) to the visual presentation of word lists for ISR and IFR. Specifically, we presented participants with sequences of 7 written words. The interval before the first item and after the last item was fixed and unfilled, leaving three inter-item intervals that contained an unfilled 100 ms pause (short unfilled temporal interval) and three inter-item intervals that contained an unfilled 1000 ms pause (long unfilled temporal interval). Recall was spoken and in any order for IFR but in forward serial order for ISR, with participants indicating omissions in ISR by saying "blank".

Each participant performed only one task (IFR or ISR) but performed blocks with digit-filled intervals and blocks with unfilled temporal intervals. The orders of the two types of temporal isolation method were counterbalanced across participants.

Method

Participants

A total of 48 participants from University of Essex took part in this experiment in exchange for £6.

Materials and apparatus

These were identical to those used in Experiments 1 and 2 except a subset of 744 words (310 words for the digit-filled interval trials and 434 words for the unfilled temporal interval trials) were randomly selected for each participant from the Toronto Word Pool (Friendly et al., 1982).

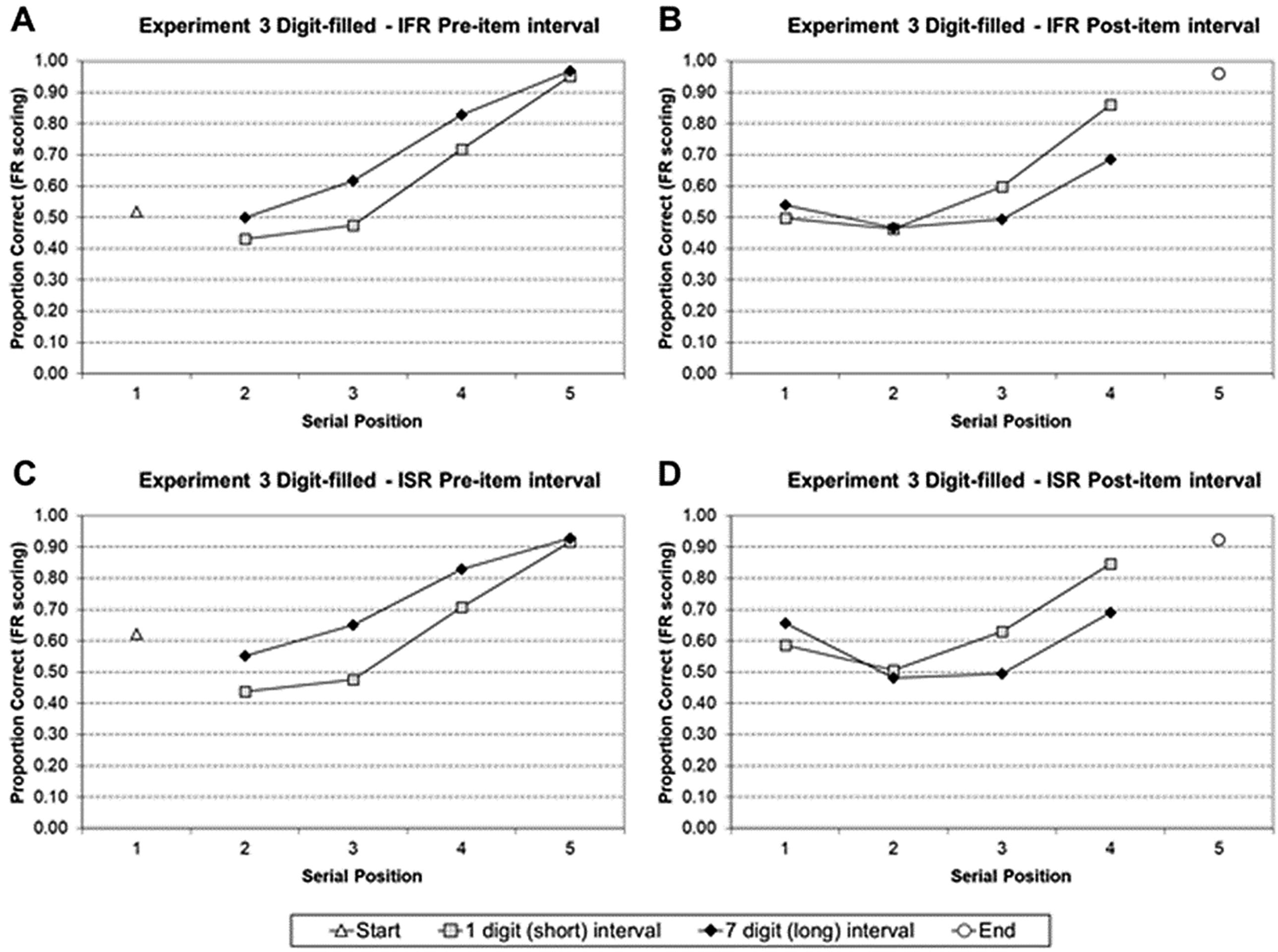

Fig. 6. Data from Experiment 3 digit filled intervals: Serial position curves for IFR and ISR using FR scoring as a function of pre-item intervals in Panels A and C respectively, and as a function of post-item intervals in Panels B and D respectively.

Design

The experiment used a mixed-design. The between-subjects independent variable was task type with two levels (IFR and ISR). There were three within-subjects independent variables. The first within-subjects independent variable was the temporal isolation method used with two levels (digit-filled or unfilled temporal intervals). The second within-subjects independent variable was the duration of the inter-stimulus interval with two levels (short and long). The third within-subjects independent variable was the serial position of the words with five levels (SPs1-5) in the digit-filled interval isolation method and seven levels (SPs1-7) in the unfilled temporal interval isolation method. The main dependent variables were the proportion of words recalled in any order (*FR scoring*) and in the correct serial position (*SR scoring*).

Procedure

Participants were randomly allocated into one of two groups, each containing 24 participants: IFR or ISR. All participants were tested individually and received two practice trials (one with digit-filled intervals and one with unfilled temporal intervals). There were 120 experimental trials split up into four blocks each containing 30 trials (either two blocks with digit-filled intervals followed by two blocks with unfilled temporal intervals, or the reversed order). The procedure with digit-filled intervals was based on Experiments 1 and 2 with shorter lists. The procedure with unfilled temporal intervals was adapted from Farrell et al. (2011, Experiment 2).

The digit-filled interval trials contained four inter-stimulus intervals, occurring between each word (there was no interval before the first word and a fixed unfilled temporal interval after the last word). These four inter-stimulus intervals consisted of short (1 digit) and long (7 digits) intervals each repeated twice. Each participant received 10 repetitions of the six possible permutations, and the order of their assigned temporal isolation sequences was randomised over the two blocks and for each participant.

Each digit-filled interval trial started with a blank screen for 1000 ms. A fixation cross was then displayed for 1100 ms (550 ms on-screen and 550 ms off-screen) with no pre-item interval before the first word. Each word was displayed for 700 ms (550 ms on-screen followed by a 150 ms off-screen). The four inter-stimulus intervals were filled with either one or seven digits. Each digit was displayed for 550 ms (400 ms on-screen followed by a 150 ms off-screen). Participants were instructed to read aloud both the digits and the words as they were presented. Following a fixed unfilled post-item interval of 550 ms after the last word, a white box appeared in the centre of the screen indicating the start of recall. Recall was written in a large square of an otherwise empty response sheet. Participants were instructed to write as many of the five words as they could remember, either in any order (IFR) or in the same order as they had been presented (ISR). They could write from left to right or from top to bottom. For ISR they were required to try to start with the first item and say "blank" to indicate any omission.

The unfilled temporal interval trials contained six inter-stimulus intervals, occurring between each word (there was no interval before the first word and a fixed unfilled temporal interval after the last word). These six inter-stimulus intervals consisted of short (100 ms) and long

(1000 ms) intervals each repeated three times. Each participant received three repetitions of the 20 possible permutations, and the order of their assigned temporal isolation sequences was randomised over the two blocks and for each participant.

Each unfilled temporal interval trial started with a blank screen for 1000 ms. A fixation cross was then displayed for 1550 ms (1000 ms on-screen and 550 ms off-screen) with no pre-item interval before the first word. Each word was displayed for 700 ms (550 ms on-screen followed by a 150 ms off-screen). The six unfilled inter-stimulus intervals were either short (100 ms) or long (1000 ms). Participants were instructed to read the words silently as they were presented. Following a fixed unfilled post-item interval of 550 ms after the last word, a white box appeared in the centre of the screen indicating the start of recall. Recall was spoken and recorded using the Audacity application for later transcription. Participants were instructed to recall as many of the seven words as they could remember, either in any order (IFR) or in the same order as they had been presented (ISR). For ISR they were required to try to start with the first item and say “blank” to indicate any omission.

In both types of inter-stimulus interval, the participants’ recall was self-paced, and there was an opportunity to take a break at the end of each block.

Results

A total of 8.5% of the responses were errors and were discarded.

The effect of total temporal isolation interval on the proportion of correctly recalled words

Fig. 1E shows the mean proportion of words recalled in IFR and ISR (using FR scoring) as a function of the total temporal isolation with both digit-filled and unfilled temporal intervals. Fig. 1F shows these same data using SR scoring. Table 3 summarises the findings of four 2 (task: IFR or ISR) × 3 (total temporal isolation interval: Short/Short, Short/Long, and Long/Long) mixed ANOVAs conducted on the proportion of words correctly recalled as a function of total temporal isolation interval for both the digit-filled and unfilled temporal intervals using FR and SR scoring. The short/long total temporal isolation interval refers to both a short pre-item and long post-item interval pairing and also a long pre-item and short post-item interval pairing.

In all four analyses, the mean proportion of words recalled increased with increasing total temporal isolation, and there were no interactions between task and total temporal isolation. For the trials with the digit-filled intervals, the linear contrast for the main effect of total temporal isolation was significant and positive with FR scoring, $F\,(1, 46) = 5.09$, $MSE = .006$, $\eta_p^2 = .100$, $p = .029$, and SR scoring, $F\,(1, 46) = 13.5$, $MSE = .005$, $\eta_p^2 = .227$, $p = .001$. Similarly, for the trials with the unfilled temporal intervals, the linear contrast for the main effect of total temporal isolation was significant and positive with FR scoring, $F\,(1, 46) = 5.66$, $MSE = .006$, $\eta_p^2 = .110$, $p = .022$, and SR scoring, $F\,(1, 46) = 4.75$, $MSE = .002$, $\eta_p^2 = .094$, $p = .034$. The mean proportion of words recalled using SR scoring was significantly greater in ISR than IFR for both digit-filled and unfilled temporal intervals, and the mean proportion of words recalled using FR scoring was significantly greater in IFR than ISR with unfilled temporal intervals but not digit-filled intervals.

Overall, for both digit-filled and unfilled temporal intervals there was a greater proportion of words correctly recalled with *increasing* total temporal intervals, which did not interact with task.

Analysis of effect of digit-filled intervals on the serial position curves as a function of pre- and post-item interval

Fig. 6 shows the serial position curves for the IFR and ISR tasks (using FR scoring) for the 5-word trials with the digit-filled intervals. The top panels show the serial position curves from the IFR group; the bottom panels show the serial position curves from the ISR group. The left-hand panels show the serial position curves as a function of the pre-item interval whereas the right-hand panels show the serial position curves as a function of the post-item interval.

Table 9
Summary of the ANOVA tables from analyses conducted on the serial position curves as a function of temporal isolation interval from Experiment 3 digit-filled intervals.

Experiment 3 Digit-filled intervals	*df*	*MSE*	*F*	η_p^2	*p*
SPC as a function of pre-item interval (FR scoring)					
Task	1, 46	.097	.001	< .001	.974
Pre-item interval	1, 46	.007	123.6	.729	< .001
SP	1.59, 73.0	.053	150.6	.766	< .001
Task × pre-item interval	1, 46	.007	1.59	.033	.213
Task × SP	1.59, 73.0	.053	.705	.015	.466
Pre-item interval × SP	2.41, 111.0	.007	15.6	.253	< .001
Task × pre-item interval × SP	2.41, 111.0	.007	.545	.012	.614
SPC as a function of post-item interval (FR scoring)					
Task	1, 46	.191	.648	.014	.425
Post-item interval	1, 46	.011	31.9	.409	< .001
SP	1.85, 85.2	.048	50.0	.521	< .001
Task × post-item interval	1, 46	.011	.022	< .001	.883
Task × SP	1.85, 85.2	.048	1.76	.037	.181
Post-item interval × SP	3, 138	.007	33.0	.417	< .001
Task × post-item interval × SP	3, 138	.007	.709	.015	.548
SPC as a function of pre-item interval (SR scoring)					
Pre-item interval	1, 23	.006	88.5	.794	< .001
SP	1.46, 33.5	.088	54.9	.705	< .001
Pre-item interval × SP	3, 69	.006	11.7	.337	< .001
SPC as a function of post-item interval (SR scoring)					
Post-item interval	1, 23	.014	5.02	.179	.035
SP	1.52, 35.0	.078	15.9	.409	< .001
Post-item interval × SP	3, 69	.009	24.8	.518	< .001

The findings of a 2 (task: IFR and ISR) × 2 (interval: short and long) × 4 (serial position, SPs 2–5) mixed ANOVA conducted on the pre-item intervals (Fig. 6 left-hand panels) and a 2 (task: IFR and ISR) × 2 (interval: short and long) × 4 (serial position, SPs 1–4) mixed ANOVA conducted on the post-item intervals (Fig. 6 right-hand panels) are summarized in the upper subtables of Table 9. Consistent with Experiments 1 and 2 which also used the digit-filled intervals, there were recall advantages in both IFR and ISR when there were long pre-item intervals and short post-item intervals.

In the analyses of the pre-item intervals with FR scoring, the patterns of data in the IFR and ISR tasks were highly similar. There were significant recency effects in both tasks across SPs 2–5, with recall advantages for longer pre-item intervals across SPs 2–4. In the analyses of the post-item intervals with FR scoring, the patterns of data in the IFR and ISR tasks were also highly similar. There was significant 1-item primacy and significant recency effects in both tasks and there were recall advantages for shorter post-item intervals across the later serial positions.

Fig. 7 shows the effect of these pre-item intervals (Fig. 7A) and post-item intervals (Fig. 7B) on ISR performance using SR scoring. The overall pattern of data with SR scoring resemble the data with FR scoring in Fig. 6C and D. The findings of a 2 (interval: short and long) × 4 (serial position, SPs 2–5) within-subjects ANOVA conducted on the pre-item intervals (Fig. 7 left-hand panel) and a 2 (interval: short and long) × 4 (serial position, SPs 1–4) within-subjects ANOVA conducted on the post-item intervals (Fig. 7 right-hand panel) are summarized in the lower subtables of Table 9. Consistent with the earlier analyses using FR scoring, the analyses showed that there were recall advantages in ISR (using SR scoring) when there were long pre-item intervals and short post-item intervals.

In the analyses of the pre-item intervals with SR scoring, there were again significant recency effects across SPs 2–5, with recall advantages for longer pre-item intervals across SPs 2–4. In the analyses of the post-item intervals with SR scoring, there was a significant 1-item primacy

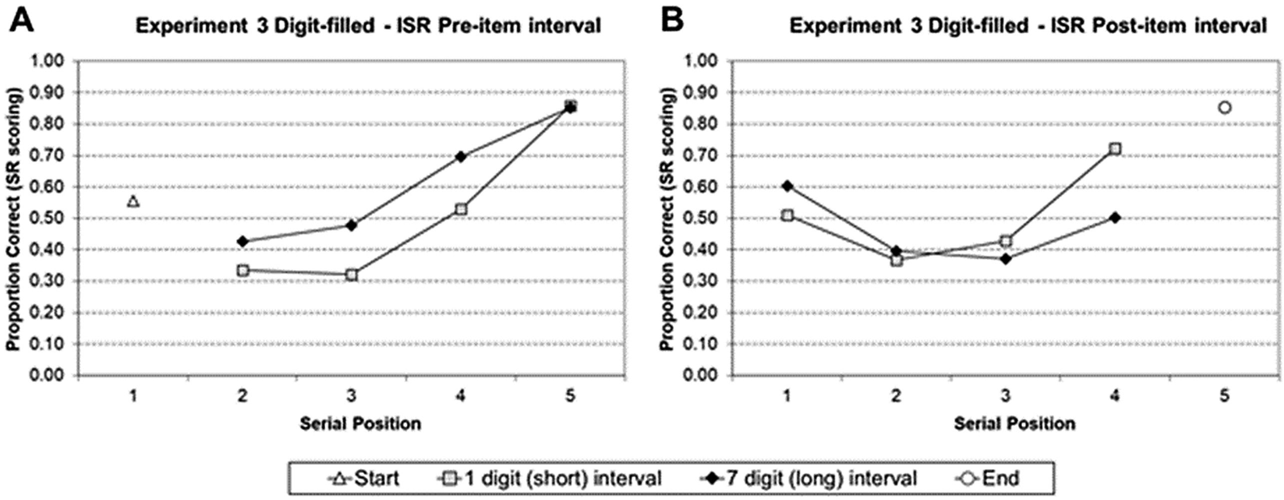

Fig. 7. Data from Experiment 3 digit filled intervals: Serial position curves for ISR using SR scoring as a function of pre-item intervals in Panel A, and as a function of post-item intervals in Panel B.

effect and a 1-item recency effect, and a recall advantage for the shorter post-item interval at SP4.

Overall, there were similar effects in IFR and ISR: in both tasks using digit-filled intervals, there were recall advantages at the end of the list for words preceded by *longer* pre-item intervals and *shorter* post-item intervals.

Analysis of effect of unfilled temporal intervals on the serial position curves as a function of pre- and post-item interval

Fig. 8 shows the effect of temporal isolation on the serial position curves for the IFR and ISR tasks (using FR Scoring) for the 7-word trials with the unfilled temporal intervals. The top panels show the serial position curves from the IFR group; the bottom panels show the serial

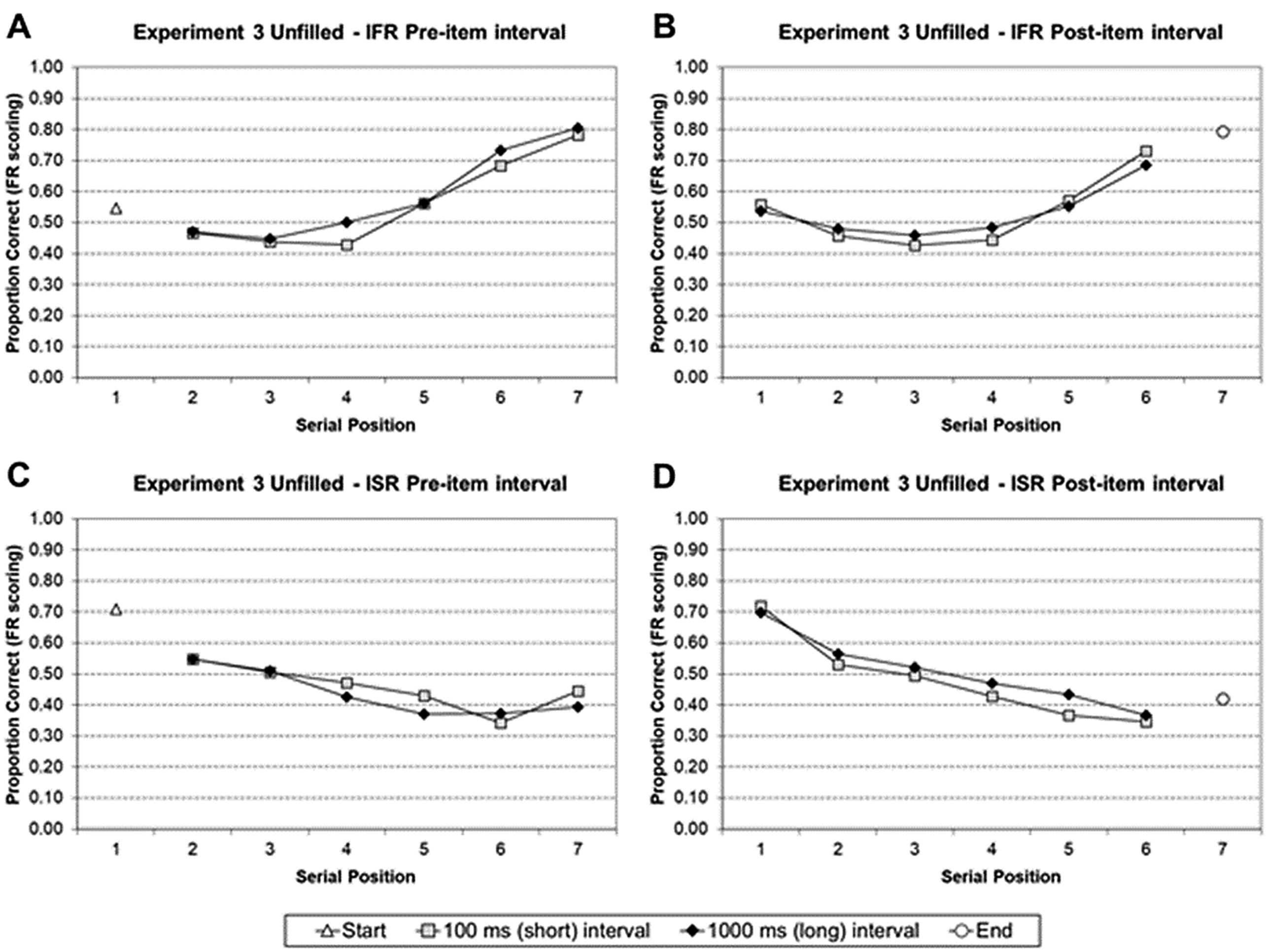

Fig. 8. Data from Experiment 3 unfilled temporal intervals: Serial position curves for IFR and ISR using FR scoring as a function of pre-item intervals in Panels A and C respectively, and as a function of post-item intervals in Panels B and D respectively.

Table 10
Summary of the ANOVA tables from analyses conducted on the serial position curves as a function of temporal isolation interval from Experiment 3 unfilled temporal intervals.

Experiment 3 Unfilled temporal intervals	*df*	*MSE*	*F*	η_p^2	*p*
SPC as a function of pre-item interval (FR scoring)					
Task	1, 46	.094	24.5	.348	< .001
Pre-item interval	1, 46	.015	.107	.002	.745
SP	1.84, 84.8	.087	8.84	.161	< .001
Task × pre-item interval	1, 46	.015	5.20	.102	.027
Task × SP	1.84, 84.8	.087	30.6	.400	< .001
Pre-item interval × SP	5, 230	.008	1.72	.036	.132
Task × pre-item interval × SP	5, 230	.008	1.52	.032	.183
SPC as a function of post-item interval (FR scoring)					
Task	1, 46	.129	1.56	.033	.218
Post-item interval	1, 46	.008	4.23	.084	.045
SP	2.05, 94.1	.068	13.3	.225	< .001
Task × post-item interval	1, 46	.008	3.02	.062	.089
Task × SP	2.05, 94.1	.068	30.7	.400	< .001
Post-item interval × SP	5, 230	.007	2.14	.044	.062
Task × post-item interval × SP	5, 230	.007	1.32	.028	.255
SPC as a function of pre-item interval (SR scoring)					
Pre-item interval	1, 23	.008	1.29	.053	.267
SP	1.77, 40.8	.071	32.3	.584	< .001
Pre-item interval × SP	5, 115	.006	.987	.041	.429
SPC as a function of post-item interval (SR scoring)					
Post-item interval	1, 23	.008	11.4	.331	.003
SP	1.74, 39.9	.067	85.8	.789	< .001
Post-item interval × SP	5, 115	.006	1.62	.066	.162

position curves from the ISR group. These data with the unfilled intervals show more typical task-specific serial position curves. The serial position curves are more bowed in IFR, and there is more extended primacy and limited recency in ISR. The left-hand panels show the serial position curves as a function of the pre-interval whereas the right-hand panels show the serial position curves as a function of the post-interval.

The findings of a 2 (task: IFR and ISR) × 2 (interval: short and long) × 6 (serial position, SPs 2–7) mixed ANOVA conducted on the pre-item intervals (Fig. 8 left-hand panels) and a 2 (task: IFR and ISR) × 2 (interval: short and long) × 6 (serial position, SPs 1–6) mixed ANOVA conducted on the post-item intervals (Fig. 8 right-hand panels) are summarized in the lower subtables of Table 10. By contrast to the digit-filled task, our initial analyses using all the responses revealed marked differences between the two tasks. We will see in the final set of analyses (below) that these differences are largely driven by the first recalls, but the full data are first analysed and reported here.

When analysing the pre-item intervals (SPs 2–7), there was no overall effect of temporal interval duration, a recall advantage for IFR over ISR (using FR scoring), with more recency and less extended primacy in IFR compared with ISR. There were also different effects of pre-item intervals on IFR and ISR: there was a recall advantage for longer pre-item intervals with IFR but a recall advantage for shorter pre-item intervals with ISR. When analysing the post-item intervals (SPs 1–6), there was a consistent recall advantage for longer post-item intervals, no overall difference in task performance, but more recency and less extended primacy in IFR compared with ISR.

Fig. 9 shows the effect of these pre-item and post-item intervals on the ISR trials with unfilled temporal intervals using SR scoring. The findings of a 2 (interval: short and long) × 4 (serial position, SPs 2–7) within-subjects ANOVA conducted on the pre-item intervals (Fig. 9 left-hand panels) and a 2 (interval: short and long) × 4 (serial position, SPs 1–6) within-subjects ANOVA conducted on the post-item intervals (Fig. 9 right-hand panels) are summarized in the lower subtables of Table 10.

The overall pattern of data with SR scoring resemble a clearer version of the data with FR scoring in Fig. 8C and 8D. When analysing the pre-item intervals (SPs 2–7), there was extended primacy effect in ISR with no effect of temporal interval duration. When analysing the post-item intervals (SPs 1–6), there was again extended primacy effect in ISR but there was a consistent recall advantage for longer post-item intervals.

Overall, there were similar effects in IFR and ISR with unfilled temporal intervals, but only once the initial responses are excluded. In both tasks, there is no effect of a pre-item interval, but there are recall advantages for words followed by *longer* post-item intervals. Using visual presentation and unfilled intervals, participants can covertly rehearse an item during and after the presentation of a stimulus, such that the TIEs are dominated by the positive effect of longer post-item intervals, where there is greater opportunity for additional rehearsal.

The Probability of First Recall (PFR)

Table A3 shows the frequencies with which participants initiated their recalls with words from particular serial positions in Experiment 3. Participants initiated recall with SP1 more often in ISR than IFR and more often in the unfilled intervals than the digit-filled intervals. However, the effect of temporal isolation could not be examined on recall of SP1 because the pre-interval interval preceding the first list item was fixed.

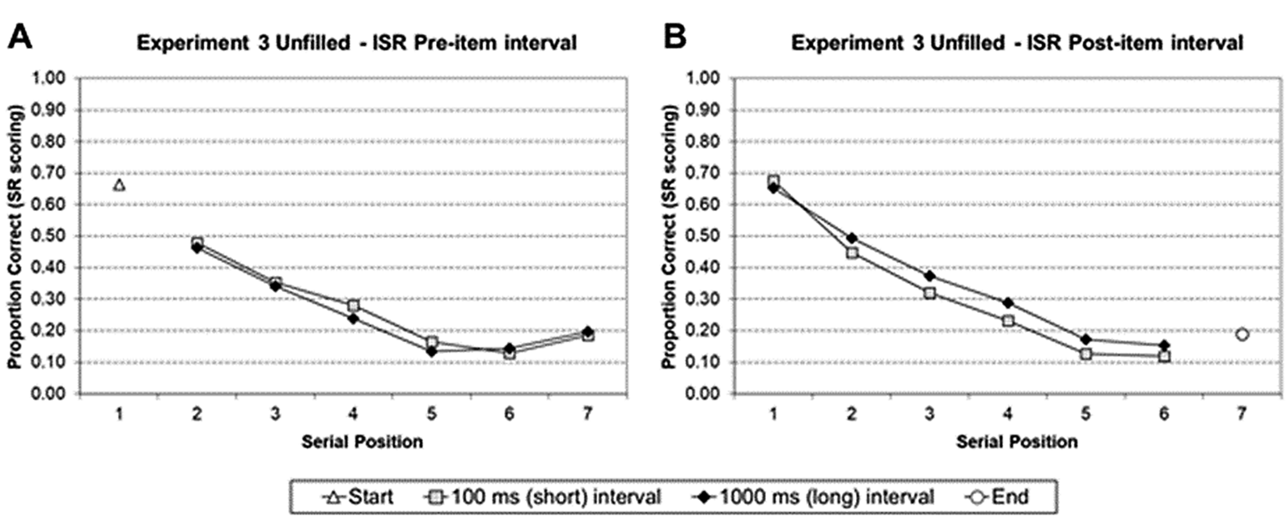

Fig. 9. Data from Experiment 3 unfilled temporal intervals: Serial position curves for ISR using SR scoring as a function of pre-item intervals in Panel A, and as a function of post-item intervals in Panel B.

Table 5 summarizes the findings of a pair of 2 (task: IFR or ISR) × 2 (pre-item interval: short and long) mixed ANOVAs conducted on the probability of initiating recall with one of the last 4 items for both digit-filled (SPs 2–5) and unfilled (SPs 4–7) temporal intervals. For both digit-filled and unfilled temporal intervals, the probability of initiating recall with one of the last 4 items was significantly lower in ISR than in IFR, and overall significantly higher for *long* pre-item intervals than short. However, an examination of the interaction between task and pre-item interval revealed that the patterns of PFRs were radically different for the two tasks. In ISR, the pre-item interval did not affect the probability of initiating recall with one of the last 4 items. However, in IFR, *long* pre-item intervals increased the probability of initiating recall with one of the last 4 items.

Thus, for both digit-filled and unfilled temporal intervals the pre-item interval has no effect on the probability of initiating recall with one of the last 4 items in ISR, but has a marked effect in IFR, with long pre-item intervals increasing the probability of initiating recall with one of the last 4 items.

The effect of pre-item interval on Lag + 1 transitions

The lower values in Table 6 show how the CRP values of Lag + 1 transitions in Experiment 3 varied as a function of the task and pre-item interval. Table 7 summarises the findings of a pair of 2 (task: IFR or ISR) × 2 (pre-item interval: short and long) mixed ANOVAs conducted to examine the proportion of Lag + 1 transitions performed for digit-filled and unfilled temporal intervals. For both the digit-filled and unfilled temporal intervals the proportion of lag + 1 transitions performed was higher for short pre-item intervals than long pre-item intervals for both IFR and ISR. For digit-filled intervals there was a significantly higher proportion of Lag + 1 transitions performed in ISR than IFR, and the increase in Lag + 1 transitions with a short pre-item interval was greater in IFR than ISR.

Thus, the tendency to transition in a forward order was lower for IFR than ISR, and, the tendency to transition in a forward order increased with *decreasing* pre-item interval.

Analysis of effect of unfilled temporal intervals on the serial position curves as a function of pre-item interval removing first recall

Analyses of the first responses (PFR) indicated that participants tended to initiate recall with items other than the first far more often in IFR than in ISR, and in the IFR trials, the initial word recalled was far more likely to be preceded by a long pre-item interval.

With the trials with digit-filled intervals, this recall advantage for first recalled items is consistent with the overall pattern of data for both IFR and ISR (Figs. 6 and 7), and when the first item is removed, the recall advantage for long pre-item intervals remain essentially unchanged across the tasks and serial position curve.

However, with the trials with unfilled temporal intervals, the recall advantage for the first recalled item (recall advantage for long pre-item intervals at SPs 2–7 in IFR) may contribute to the significant interaction between task and pre-item interval where in IFR there is a recall benefit for long pre-item intervals (Fig. 8A) whereas in ISR there is a recall benefit for short pre-item intervals (Fig. 8C). As Fig. 10 shows, when the first item recalled is removed, there are now nominal recall benefits for long pre-item intervals for both IFR and ISR. Table 11 confirms that the interaction between task and pre-item interval is now non-significant.

Discussion

Experiment 3 sought to examine TIEs in IFR and ISR using methodologies that more closely resembled classic ISR methodologies and which were more likely to generate the extended primacy in serial position curves that are characteristic of ISR. We did this by comparing

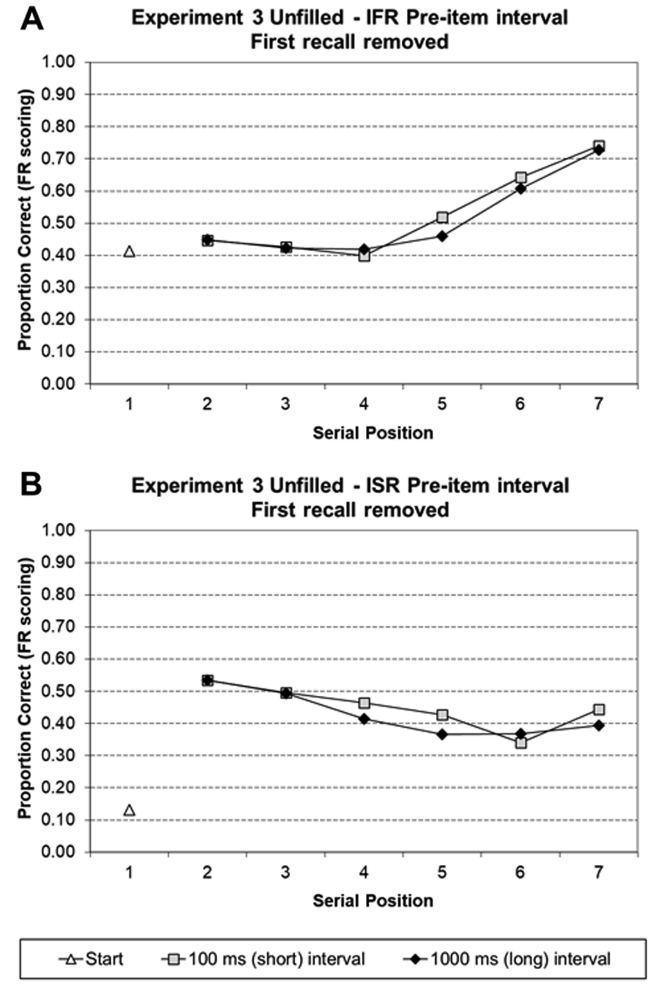

Fig. 10. Data from Experiment 3 unfilled temporal intervals: Serial position curves for IFR and ISR with the first item recalled removed using FR scoring as a function of pre-item intervals in Panels A and B respectively.

Table 11
Summary of the ANOVA tables from an analysis conducted on the serial position curves removing first recall as a function of pre-item interval from Experiment 3 unfilled temporal intervals.

Experiment 3 Unfilled temporal intervals First recall removed	*df*	*MSE*	*F*	η_p^2	*p*
SPC as a function of pre-item interval (FR scoring)					
Task	1, 46	.109	9.57	.172	.003
Pre-item interval	1, 46	.016	1.94	.041	.170
SP	1.84, 84.4	.090	8.62	.158	< .001
Task × pre-item interval	1, 46	.016	.370	.008	.546
Task × SP	1.84, 84.84	.090	23.3	.336	< .001
Pre-item interval × SP	5, 230	.009	1.43	.030	.216
Task × pre-item interval × SP	5, 230	.009	1.18	.025	.320

ISR and IFR on both 5-item trials with digit-filled intervals and 7-item trials with unfilled temporal intervals.

There were three sets of findings. First, for the first time, we found a small positive recall advantage with increased total temporal isolation. The finding of an overall effect of temporal isolation is more consistent with the classic TIE literature (e.g., Morin et al., 2010). The methodology in Experiment 3 may have contributed to this outcome as it used only short (1 digit or 100 ms) and long (7 digits or 1000 ms) temporal intervals, such that there were no intervals with 0 interval (which had tended in earlier experiments to sometimes result in slightly elevated recall) and the data were concentrated into only three total temporal isolations. It should be noted that nevertheless these overall TIEs were very modest in both methods and both tasks.

Second, with the 5-item digit-filled intervals, we broadly replicated the findings from Experiment 1 and 2. For both IFR and ISR, we found recall advantages for long pre-item intervals and recall advantages for short post-item intervals. We also found increased tendencies to initiate recall with words that were preceded by a long pre-item interval and for both tasks we found increased tendencies to make lag + 1 transitions between words that were separated by a short pre-item interval. Although we again found highly similar effects of TIE on IFR and ISR, our attempts to make the ISR data with the digit-filled intervals more typical were not entirely successful: participants did initiate ISR with SP1 on the majority of trials, but we found only 1-item primacy effects. The digit-shadowing activity extended the duration of the trials and greatly reduced the opportunity to process and rehearse the items in the inter-stimulus intervals and these factors combined to significantly weaken the characteristic primacy in the ISR serial position curves.

Third, with the 7-item unfilled temporal durations, we found recall advantages in both IFR and ISR for long post-item intervals. This finding is consistent with prior data showing recall advantages at slower presentation rates when rehearsal is not prevented (for ISR, see Tan & Ward, 2008; for IFR, see Grenfell-Essam et al., 2013; Tan & Ward, 2000). We also found characteristic serial position curves in IFR and ISR, arguably owing to the shorter duration of the trials and the opportunity to benefit from the unfilled intervals. We again found tendencies to initiate recall with words that were preceded by a long pre-item interval and for both tasks we found increased tendencies to make lag + 1 transitions between words that were separated by a short pre-item interval. When all the data were analysed, we found different effects of a pre-item interval on ISR and IFR: in IFR, there were marginal advantages for a long pre-item interval; whereas with ISR, there were marginal advantages for a short pre-item interval. However, when the initial response was removed from these analyses, there interaction between task and pre-item interval became non-significant.

General discussion

There were two main aims of our experiments examining TIEs in IFR and ISR. First, we wished to seek evidence that might encourage theoretical integration between IFR and ISR. Second, we wished to better understand the variation in the magnitudes of TIEs that have been observed in prior research, particularly given that prior research using different methodologies suggests that TIEs may be stronger in IFR but may be weaker, or even absent, in ISR.

Let us first consider the similarities and differences between IFR and ISR. Our findings support the claim that there are similar patterns of TIEs in ISR and IFR when the two tasks are compared using the same methodology. We directly compared the two tasks using digit-filled inter-stimulus intervals (that had previously been used to study TIEs with long lists in IFR) at shorter list lengths (7 word lists, Experiment 1), longer list lengths (17 word lists, Experiment 2), and very short lists (5 word lists, Experiment 3). In all three experiments, we found similar patterns of TIEs in IFR and ISR. This occurred when we examined the effect of the duration before a word (the pre-item interval), when we examined the effect of the duration after a word (the post-item interval) and when we summed these two intervals to compare the effects of the total temporal isolation interval. Indeed, it was very rare using a digit-filled interval that we found any interaction between task and the duration of the inter-stimulus interval.

There was, however, some evidence for task differences when TIEs were examined using an unfilled temporal interval in Experiment 3 (a method adapted from studies of TIE with shorter lists in ISR, Farrell et al., 2011). When participants read silently a list of 7 words which were separated by short (100 ms) or long (1000 ms) inter-stimulus intervals, we found similar effects of total temporal isolation intervals and post-item intervals, but we found differences in the effect of the pre-item intervals between the tasks. Specifically, we found that IFR tended to benefit from longer pre-item intervals, but ISR tended to benefit (non-significantly) from shorter pre-item intervals. However, even this difference can be accounted for if one allows the first response to be a special case. In ISR, participants tend to initiate recall with the first list item (as instructed), but in IFR, they tend to initiate recall with a later list item that was preceded by a longer pre-item interval. When this initial recall is excluded from the analysis, the recall benefit of longer pre-item intervals in IFR is reversed, and there is no longer an interaction between task and pre-item interval.

Together, our findings suggest that differences in methodology rather than differences in tasks are primarily responsible for prior reported differences in the magnitude of TIEs. Our more similar TIEs are consistent with an emerging body of evidence (e.g., Bhatarah et al., 2008, 2009; Grenfell-Essam & Ward, 2012; Grenfell-Essam et al., 2017; Spurgeon et al., 2014; Ward et al., 2010) that suggest that IFR and ISR are more similar than different when the two tasks were compared under similar methodologies, list lengths, and scoring systems. As such, our data broadly supports those theories that already account for both IFR and ISR, such as Brown et al. (2007) and Farrell (2012), and encourages future theoretical integration of IFR and ISR.

Let us now consider the exact patterns of TIEs that we observed. First, we found only modest increases, at best, in recall with increases in the overall temporal isolation interval. This finding was surprising and at first appears contrary to theories that propose that recall benefits from greater temporal distinctiveness (Brown et al., 2007) or from easier discrimination in temporal context (Glenberg, 1987). However, the main reason for this modest effect of overall temporal isolation interval is that we observed both *positive* and *negative* effects of increasing temporal intervals, with different complex and nuanced patterns of TIEs at different serial positions.

It is more diagnostic to consider the TIEs with digit-filled intervals, because any effects of rehearsal are minimized using this method. With digit-filled intervals, we found recall advantages for words preceded with *longer* pre-item intervals. These recall advantages for longer pre-item intervals were limited to the second half of the list in Experiments 1 and 3, and present throughout the list in Experiment 2. We attribute these advantages to the greater temporal distinctiveness (Brown et al., 2007) or greater contextual discrimination (Glenberg, 1987) afforded to items that are more temporally isolated. These advantages are particularly informative as they cannot be attributed to differences in post-item processing (such as elaboration or rehearsal) because the item had not yet been presented. A temporal distinctiveness account also offers a good explanation for the heightened tendency to initiate recall with a word preceded by a longer pre-item interval.

However, we also found recall advantages for words followed by *shorter* post-item intervals. These effects tended to be more pronounced in the second half of the list in all three experiments. We also found an increased tendency to make Lag + 1 transitions between successively presented list items when there was a shorter inter-stimulus interval between the pair of words. These recall advantages for shorter temporal intervals are less easy for theories that assume recall benefits from greater temporal distinctiveness (Brown et al., 2007) or greater contextual discrimination (Glenberg, 1987), especially in the absence of an account of the order of responses.

The patterns of TIEs before and after the individual list items are less diagnostic in the unfilled temporal intervals because it is more likely that additional rehearsal or elaborative processing of earlier items could be carried out during and after the presentation of later list items. Unlike the unfilled temporal intervals used by Farrell et al. (2011), we used visual silent presentation (rather than auditory presentation) which might further have encouraged the incorporation of new items into a rehearsed sequence (e.g., Macken, Taylor, Kozlov, Hughes, & Jones, 2016). Nevertheless, we still observed a heightened tendency to initiate recall with a word preceded by a longer pre-item interval and a greater tendency to make Lag + 1 transitions between successively presented list items when there was a shorter inter stimulus interval between the pair of words.

A number of theoretical frameworks propose recall advantages for items that are distinctive and also items that are highly related to others (e.g., Einstein & Hunt, 1980; Hunt & McDaniel, 1993). However, when one considers the effects of temporal or contextual distinctiveness, there are two main contenders.

First, retrieved context models of free recall (Howard & Kahana, 2002; Lohnas et al., 2015; Polyn et al., 2009; Sederberg et al., 2008) assume that items are associated at encoding with a gradually-changing representation of temporal context. At the end of the list, the temporal context at test is more similar to that associated with those items toward the end of the list (such that there is enhanced probability of initiating recall with a recency item). Critically, once an item is retrieved, the study context associated with the retrieved item is also retrieved and this is used as a cue, supporting the retrieval of neighboring items that share similar contextual states. Inspired by the predictions of a retrieved context model, Polyn et al. (2019) presented participants with lists of 15 words separated by arithmetic-filled interstimulus intervals of between 6 and 23 s that expanded and contracted cyclically throughout the list. Polyn et al. failed to find a recall benefit for temporally isolated items, but found that the forward-order asymmetry in recall (promoting Lag + 1 transition) increased when the interval between the items was reducing, a finding similar to that in our data. Unfortunately, the retrieved context models have not as yet been applied to ISR, and have a tendency to over-predict the magnitude of the recency effect in very short lists (e.g., Ward & Tan, 2019; Ward et al., 2010).

Second, a temporal grouping explanation may also explain our nuanced pattern of TIEs (Farrell et al., 2011; Farrell, 2012). Farrell (2012) has proposed a model of short-term memory and episodic memory that can account for data from a wide variety of tasks including IFR and ISR. Central to the model, is the idea that participants parse a continuous sequence of items into a series of *ad hoc* subgroups or clusters. In the absence of grouping instructions, the temporal organisation may be influenced by the serial position of the list item and the sequences of temporal pauses. Following Farrell (2012), the first item of the list will always be the first item of the first subgroup. However, participants may elect to initiate second and subsequent subgroups when the randomized digit structure fortuitously generates a favourable set of pre-item and post-item intervals (Hartley et al., 2016). Following the discussion of Farrell et al. (2011, p. 583), a longer pre-item interval may encourage grouping by forming a temporal discontinuity that suggest a group boundary (encouraging participants to terminate the current subgroup and create a new subgroup), whereas a shorter pre-item interval may further encourage the continuation of encoding within a subgroup. Spurgeon et al. (2015) have shown that participants are more likely to initiate IFR and ISR with the first item within a group (particularly the first item of the most recent group); they then tend to make heightened Lag + 1 transitions to subsequent successive items within a group.

Our findings are also supported by further consideration of the predictably increasing and decreasing schedules of total isolation intervals when rehearsal is prevented. As shown in Brown et al. (2006, Experiment 1), the decreasing schedules typically show recall advantages early in the list when the pre-item intervals in the decreasing schedules are much longer than the pre-item intervals in the increasing schedules, but the recall advantages reverse in the middle of the list when the pre-item intervals in the increasing schedules become longer than the pre-item intervals in the decreasing schedules. Finally, there is a recall advantage at the end of the list for the decreasing schedules, because recall benefits at the end of the list from far shorter post-item intervals.

Summary and conclusions

We have presented the findings of three experiments which examined TIEs in immediate memory tasks using shorter and longer lists. We found only modest recall advantages for words that are temporally isolated based on the total temporal isolation interval. Rather, we found recall advantages for longer pre-item and shorter post-item intervals, which we interpret within a grouping account. Since we show broadly similar TIEs in ISR and IFR, we argue our findings encourage greater theoretical integration between these tasks, especially for shorter list lengths.

Acknowledgments

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Appendix A

See Tables A1–A3.

Table A1
Data from Experiment 1: The distribution of the first words recalled on each trial as a function of task, pre-item interval and serial position. Note that the *Italicized values* show the frequencies of trials in which recall is initiated with one of the last four presented words.

Serial Position	Pre-item interval digits											
	IFR				ISR-free				ISR			
	0	1	3	7	0	1	3	7	0	1	3	7
1	73	59	49	69	14	20	20	26	221	176	168	181
2	24	17	14	23	7	9	6	9	58	60	57	57
3	18	19	20	20	9	9	11	8	62	56	60	71
4	*11*	*19*	*26*	*40*	*4*	*9*	*11*	*20*	*64*	*68*	*84*	*95*
5	*28*	*43*	*60*	*99*	*15*	*28*	*69*	*103*	*58*	*71*	*99*	*138*
6	*68*	*119*	*147*	*200*	*54*	*88*	*145*	*168*	*56*	*73*	*76*	*107*
7	*172*	*261*	*345*	*424*	*283*	*360*	*426*	*475*	*23*	*33*	*35*	*56*

Table A2
Data from Experiment 2: The distribution of the first words recalled on each trial as a function of task, pre-item interval and serial position. Note that the *Italicized values* show the frequencies of trials in which recall is initiated with one of the last four presented words.

Serial Position	Pre-item interval digits																							
	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
	IFR								ISR-free								ISR							
1	11								9								203							
2						1	1			1		3					2		2	3	4	3	4	2
3					1			1		1							4	1	3	1	2	2	4	4
4		1			1						1					1	2		2	2	2		4	2
5																	1	1	4		1	2	4	3
6							2					1					1	1		5	2	5	1	1
7											1						3		4	1	3	2	2	1
8			1				1		1			1			1		1		1	2	1	2	1	3
9						1						1		1		1	2	1	2		3	1	5	2
10					1			1	1							1	2		1		1	1	2	1
11		1															2	1	1	3			1	1
12			1							1		1					1			1	1		2	1
13			1		1	1	1										4	1	1	3	2		2	5
14		*1*	*2*	*2*	*1*		*1*	*1*							*1*		*1*	*2*	*3*	*3*	*1*	*4*	*3*	*1*
15	*2*		*6*	*4*	*2*	*1*	*1*	*3*							*1*	*5*	*2*	*2*	*1*	*4*	*2*	*4*	*4*	*6*
16	*7*	*8*	*5*	*10*	*11*	*5*	*10*	*13*	*4*	*2*	*3*	*8*	*2*	*7*	*3*	*5*			*6*	*4*	*5*	*3*	*1*	*2*
17	*19*	*43*	*48*	*44*	*44*	*40*	*50*	*61*	*39*	*50*	*59*	*63*	*46*	*57*	*46*	*49*								*3*

Table A3
Data from Experiment 3: The distribution of the first words recalled on each trial as a function of task, pre-item interval and serial position. The upper sub-table reflects the data from digit-filled intervals and the lower sub-table reflects the data from unfilled temporal intervals. Note that the *Italicized values* show the frequencies of trials in which recall is initiated with one of the last four presented words.

Temporal isolation method	Serial Position	Pre-item interval digits					
		0	Short	Long	0	Short	Long
		IFR			ISR		
Digit-filled intervals	1	158			801		
	2		*29*	*35*		*36*	*21*
	3		*38*	*86*		*17*	*15*
	4		*91*	*222*		*1*	*4*
	5		*276*	*463*			
Unfilled temporal intervals	1	330			956		
	2		27	29		19	20
	3		14	33		14	22
	4		*34*	*101*		*8*	*14*
	5		*66*	*136*		*3*	*6*
	6		*82*	*232*		*2*	*4*
	7		*113*	*205*		*2*	

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jml.2019.104049.

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