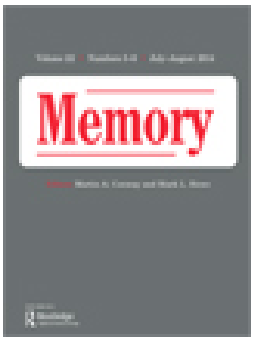

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The long-term recency effect in recognition memory

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Three classes of theories explain the recency effect: the modal model, single-store models, and the composite view, which integrates the two positions. None could explain the absence of a long-term recency effect in recognition memory in previous studies. We suggest that prior work did not obtain a recency effect because testing used a multiple-probe rather than a single-probe recognition procedure. Here we tested memory using a single-probe recognition procedure. Experimental conditions included an immediate test, a delayed test after a filled interval, and a continuous-distractor paradigm in which the same filled delay preceded the first word and followed every study word. The long-term recency effect in continuous-distractor recognition was equivalent to the recency effect in immediate recognition. Its absence in the delayed recognition condition demonstrated that it was not attributed to the use of a putative short-term memory store. Single-store models and the composite view can account for this novel finding.

The serial-position curve in free-recall tasks is one of the most robust findings in memory research. The higher probability of recall of early (primacy) and late (recency) list items, as compared to items from the middle of the list (e.g., Murdock, 1962; Postman & Phillips, 1965), has intrigued memory researchers for more than a century (Nipher, 1878). Three classes of theories provide explanations for the recency effect. We show that none of them can explain the absence of a recency effect in the continuous-distractor recognition paradigm (Bjork & Whitten, 1974; Glenberg & Kraus, 1981; Poltrock & Macleod, 1977). We suggest that prior studies that used the continuous-distractor paradigm did not obtain a recency effect because testing used a multiple-probe procedure rather than a single-probe recognition procedure. We explain how this choice affected the recency effect and show that when we correct this methodological flaw, the recency effect reappears. We then evaluate the three theoretical positions to examine which one could account for the novel finding.

The mechanisms responsible for the recency effect have primarily been investigated with the free-recall task. The modal model provides the textbook explanation for the recency effect in free recall (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965). The modal model, in its many versions (e.g., Raaijmakers & Shiffrin, 1981), postulated two memory stores. According to all dual-store models, late list items are retrieved from a highly accessible short-term memory store. This gives the late list items an advantage over

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earlier list items, which are no longer stored in this limited-capacity buffer, but instead retrieved with effort from a long-term memory store.

An important prediction of dual-store models is that whenever participants engage in mental activity during the retention interval, the recency effect should be attenuated (Glanzer & Cunitz, 1966; Postman & Phillips, 1965). This happens in the delayed free-recall task, in which participants perform a distractor task during the retention interval, such as solving arithmetic problems for 10–30 seconds. Apparently, the end-of-list distractor task displaces the final list items from the postulated short-term memory store. Therefore, at test, final list items can only be retrieved from long-term memory, thereby losing their unique advantage. Surprisingly, the recency effect reappears even in a delayed test when all study items are separated, as when participants engage in the distractor task prior to the encoding of each list item (i.e., inter-stimulus interval) and following the last item (i.e., retention interval). The recency effect in this task is termed the long-term recency effect, because according to dual-store models, the end-of-list distractor task displaces items from the postulated short-term store, thereby ensuring that all items are retrieved from long-term memory.

Long-term recency effects are obtained not only in the laboratory (Bjork & Whitten, 1974), where the paradigm is referred to as the continuous distractor task, but also in real-life situations, e.g., when at the end of the season, rugby players recalled their late-season matches better than matches in the middle of the season (Baddeley & Hitch, 1977). While dual-store models successfully account for the recency effect in immediate free recall and its attenuation in delayed free recall, they cannot explain why it is manifested in continuous-distractor free recall. The finding of long-term recency was one of the most important reasons for the proclamation of the "demise of short-term memory" (Crowder, 1982, p. 291; Crowder, 1993), and the rise of single-store theories, which account for serial position effects through processes occurring in a unitary, long-term memory store.

Single-store theories proposed that a single, scale-invariant mechanism is responsible for serial position effects. To account for recency, distinctiveness-based single-store theories suggested that relative temporal distinctiveness, computed according to the time lag between test and the study of each list item, determines the relative competitiveness of an item's memory trace at retrieval (Bjork & Whitten, 1974; Glenberg & Swanson, 1986; Knoedler, Hellwig, & Neath, 1999; Murdock, 1960; Nairne, Neath, Serra, & Byun, 1997; Neath, 1993b; Neath & Crowder, 1990; Neath & Knoedler, 1994). On an immediate free-recall test, late-list items (i.e., recency items) are relatively more distinct, and are thus more easily retrieved. As an alternative, context-based single-store theories suggest that the similarity of study–test contexts is strongly affected by the study–test time lag (Glenberg, Bradley, Kraus & Renzalia, 1983; Glenberg et al., 1980; Glenberg & Kraus, 1981; Howard & Kahana, 1999, 2002). On an immediate free-recall test, when all list items compete for retrieval, recency items share more contextual units with the test context. Assuming that the contextual units serve as retrieval cues for the studied items, recency items can be more easily retrieved.

In delayed free recall, both distinctiveness-based and context-based single-store theories claim that the distractor-filled retention interval between study and test places recency items at a particular disadvantage. That is, given a sufficiently long retention interval, the relative distinctiveness of recency items may be reduced, or the similarity of the retrieval context to the context of the recency items may be reduced so as to make context an ineffective retrieval cue.

In the continuous-distractor task, all list items are, in general, less memorable than in immediate free recall. However, relative to mid-list items, recency items are still more distinct and share more contextual units with the test context. This is because in continuous-distractor free recall the interpolated distractor activity is evenly spaced across items, so it does not place recency items at a disadvantage in the same way that it does in delayed free recall. In other words, the relative distinctiveness, and the amount of contextual similarity, of items across all list positions are similar in immediate and continuous-distractor paradigms, which results in similar recency effects.

Dual-store theories should not change their predictions when memory is tested using a recognition task rather than a free-recall task. Dual-store theories predict a recency effect in immediate tests of recognition. In contrast, in delayed recognition and continuous distractor recognition no recency effect is predicted by these models, because of the displacement of recency items from the postulated short-term store during the distractor-filled retention interval. Unlike the free-recall results, which were problematic for these theories (i.e., the existence of a recency effect in the continuous-distractor task), the predictions of dual-store models have been confirmed when memory was tested with recognition. A recency effect is found in immediate recognition (e.g., Crites, Devine, Lozano, & Moreno, 1998; Monsell, 1978; Neath, 1993b; Norman & Wickelgren, 1965), and is reduced in delayed recognition (Christie & Phillips, 1979; Forrin & Cunningham, 1973; Jahnke & Erlick, 1968). Critically, studies in three laboratories have found no recency effect in continuous-distractor recognition (Bjork & Whitten, 1974; Glenberg & Kraus, 1981; Poltrock & Macleod, 1977).

With regard to single-store models, Greene (1986) argued that because such theories describe the recency effect as a retrieval phenomenon, they would predict that no recency effect would be obtained in either immediate, delayed, or continuous-distractor recognition. This is because the target items on a recognition test are ‘‘copies’’ of the original studied items (i.e., copy cues), and as such are strong retrieval cues, which should ‘‘override’’ weaker, internally generated cues (Tulving, 1983). Because single-store theories argue that the advantage of recency items derives from internally generated retrieval cues (either relative distinctiveness or contextual similarity), the advantage of recency items should be eliminated when memory is tested with recognition. However, as reviewed above, while recency effects have indeed not been found in continuous-distractor recognition, they been reported in immediate recognition.

A possible rebuttal to Greene's (1986) argument, and an interpretation for the empirical data, may be that even though internally generated cues are less important in a recognition test, these might still play a role. The influence of internally generated cues on recognition memory is in line with Tulving's assertion that the copy cue is not the ultimate retrieval cue (Tulving, 1983, Tulving & Thomson, 1973). The copy cue does not provide automatic access to the memory trace (engram); instead, the decision that a certain item is ‘‘old’’ relies on a complex process of matching all available information at test with the memory trace (ecphory). This idea is supported by evidence for a recollective, search-based component in recognition memory (Aggleton & Brown, 1999; Atkinson & Juola, 1974; Jacoby, 1991; Mandler, 1980; Tulving, 1985; for review see Yonelinas, 2002), and by evidence for the effect of environmental context on recognition memory—smaller than in recall tests, but nonetheless reliable (Smith & Vela, 2001). Indeed, according to the two-process models of recognition memory, serial position could influence recollection (but not familiarity; e.g., Jones & Roediger, 1995). Thus, it is not necessary to the advantage of late list items to disappear completely in a recognition test.

The problem for single-store theories is that if they use these arguments to claim that the recency effect in immediate recognition is a result of participants' use of internally generated cues (e.g., Neath, 1993b; Schwartz, Howard, Jing, & Kahana, 2005), they should also predict a recency effect in continuous-distractor recognition. This is why single-store theories cannot consistently account for both the presence of a recency effect in immediate recognition and its absence in continuous-distractor recognition.

Table 1 summarises the predictions of single-store and dual-store models and pits them against existing data. It seems that the pattern of findings in immediate and continuous-distractor free recall and recognition is problematic for both dual- and single-store theories (see Table 1). However, a recent composite model (Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005) offers a potential solution. According to the composite model, immediate and long-term recency effects rely on partly different mechanisms. The long-term recency effect relies on long-term memory properties, such as those proposed by single-store theories. Critically, the composite view suggests that for immediate recency effects in both free recall and recognition, a short-term memory mechanism is also involved (although long-term memory mechanisms can play a supportive role). The composite view is neutral with regard to the recency effect in continuous-distractor recognition, because its explanation for the recency effects in immediate recognition does not force this view to predict a similar effect in continuous-distractor recognition.

To summarise, single-store theories of the recency effect are unable to explain why the effect is present in immediate recognition, but not in continuous-distractor recognition. This discrepancy is directly predicted by dual-store theories, but the traditional models cannot account for the analogous free-recall data. The composite view

TABLE 1
Predictions for single-store and dual-store models

	Prediction for recency effects		
Task	*Dual store*	*Single store*	*Composite view*
Recall tasks			
Immediate recall	Yes	Yes	Yes
Delayed recall	No	No	No
Continuous-distractor recall	**No**	Yes	Yes
Recognition tasks			
Immediate recognition	Yes	Yes	Yes
Delayed recognition	No	No	No
Continuous-distractor Recognition	No	**Yes**	Neutral

Predictions that do not match available data are presented in **bold** fonts.

can account for this discrepancy, but does so with a cost to parsimony (a cost it intentionally incurs; see Davelaar et al., 2005), because it has to invoke different explanations for the immediate and the long-term recency effects.

To illuminate these issues, we re-examined recognition studies of the recency effect. In the typical recognition paradigm (termed here the ‘‘multiple-probe’’ procedure; Strong, 1912), each study item is presented for a yes/no recognition test following study-list presentation. Test items are typically randomised, so it is quite likely that recency items would be probed only after participants had already seen some test items (items from earlier study-list serial positions as well as lure items). Elsewhere (Goshen-Gottstein & Talmi, 2005; Talmi, 2001) we have suggested that using a multiple-probe recognition procedure amounts to an interpolated activity between study and test, as in delayed testing paradigms, and is likely to attenuate or eliminate the recency effect.

To avoid the problem of confounding serial position with output interference or delay (see Kerr, Avons, & Ward, 1999, for similar reasoning), immediate recognition studies have sometimes used the single-probe recognition paradigm (synonymous with the ‘‘Sternberg task’’, pioneered by Sternberg, 1966). In this paradigm, each study list is followed by a single test item, or ‘‘probe’’. While the data yield per subject hour is lower, this design avoids the serious test-order confound. While many immediate recognition studies used the single-probe recognition paradigm, surprisingly, all three continuous-distractor recognition studies have used the multiple-probe procedure.

Poltrock and MacLeod (1977), Experiment 1) used a standard yes/no recognition test list which included all study-list items as well as an equal number of distractors, presented in random order; the test lasted 1 minute. Bjork and Whitten (1974), Experiment 3) actively controlled the relationship between study and test positions, but by doing so rendered the recency effect even less likely. They presented items from each input serial position the same number of times in each test-list quarter. The recognition test, which lasted 2 minutes, included 10 old items (one word from each of the word pairs studied) and 22 distractor items. Finally, Glenberg and Kraus (1981) noted that in the Poltrock and Macleod procedure ‘‘some of the terminal list items were tested toward the end of the recognition list. This is troublesome, because the size of the long-term recency effect decreases as the [retention interval] lengthens’’ (p. 3). They therefore attempted to improve the procedure by testing each one of the nine input serial positions once in each third of the recognition test, and examined recognition performance separately in each third of the test. Glenberg and Kraus did not find a long-term recency effect even when they limited the analysis to items tested in the first third of the test. Notably, recognition was tested with a three-alternative forced choice presented in a vertical array, so that even in the analysis limited to the first third of the test, participants could have seen up to nine items before they saw the item they studied in the ninth serial position. While we share their critique, we believe that Glenberg and Kraus's procedure suffered from the same weaknesses they wished to address. Clearly, to allow the recency effect in continuous-distractor recognition to appear, a single-probe rather that a multiple-probe recognition paradigm must be used.

Our earlier investigations successfully overcame the multiple-probe confound, and showed a recency effect in continuous-distractor recognition (Goshen-Gottstein & Talmi, 2006; Talmi, 2001). That study showed that the recency effect was similar in both immediate recognition and continuous-distractor recognition when a single-probe recognition procedure was used in both tasks. These effects were found in two experiments, with six-word lists (sampled with replacement in Experiment 1) and nine-word, supra-span lists (sampled without replacement in Experiment 2). The interpolated activity consisted of an arithmetic task (addition or subtraction of single digits). In Experiment 1 participants read and solved exercises out loud, and in Experiment 2 they used a key press to indicate which of two exercises presented simultaneously on the screen had the higher value. However, in neither case was a delayed condition used. Therefore, an alternative interpretation is that we found a recency effect in continuous-distractor recognition because the distractor task employed failed to clear the putative short-term memory store. This concern is amplified because in Experiment 1 we did not have objective measures of participants' performance on the distractor task, and in Experiment 2 participants were not required to vocalise their responses, so it is possible that they were able to hold on to late list items by rehearsing them in the phonological loop (Baddeley, 2003; Colle & Welsh, 1976) while performing the distractor task, using visuo-spatial sketchpad resources. Although in Experiment 2 we had objective measures showing that participants' performance on the distractor task did not differ across serial positions, this still could not prove that the distractor task depleted short-term memory resources. One way to rule out this alternative interpretation is to show that the long-term recency effect in the continuous-distractor recognition task is larger than any recency effects in a delayed recognition test.

Here we report the results of a new experiment, using a different population and stimuli (Canadian students and English words vs Israeli students and Hebrew words). Participants performed three tasks: immediate recognition, delayed recognition, and continuous-distractor recognition, in a counterbalanced order. We again used nine-word supraspan lists and a similar arithmetic judgement task as in our earlier experiment 2 (Goshen-Gottstein & Talmi, 2006; Talmi, 2001), but we now had participants read all the exercises out loud. The inclusion of the delayed recognition condition allowed us to interpret the recency effect in the continuous-distractor recognition condition, if found.

METHOD

Participants

Participants were 30 University of Toronto students (20 females, 10 males, mean age 20.86, *SD* =2.28), who were paid $60 for participating in five 1-hour sessions. Sessions were held at least 24 hours apart, within a period of 4 weeks. Two participants failed to obey instructions and four chose to discontinue after the first session; they were replaced. To increase motivation and compliance with the instructions, participants also received a small bonus ($5–$15) calculated on the basis of their individual performance.

Materials

Words for each one of the three experimental tasks—immediate recognition, delayed recognition, and continuous-distractor recognition—were randomly sampled without replacement for each participant from the same pool of 513 words (four- to seven-letters words with mean frequency of 38, *SD* =27; Kucera & Francis, 1967). Put differently, words were never repeated during the course of any one task, but were the same for each task. Words for practice trials were sampled from a separate pool of 57 words (eight-letter words with mean frequency of 40, *SD* =29).

Words were presented in black 24-point Times New Roman font. List words were presented in lower case, and the probe was presented in upper case. Words were presented on a yellow background.

The stimuli for the continuous distractor task were simple arithmetic problems of subtraction and addition of randomly sampled single digits (e.g., $4-8=$, or $3+9=$). Two exercises were presented to the left or the right of the centre of a grey screen, in black 18-point Courier New font.

Procedure

In each task, participants studied a total of 54 nine-word lists, divided into three blocks of

18 lists each. Half of the lists of each block were followed by new probes, and half by old probes. In each block, each serial position was sampled once, for a total of three times per task. In the immediate and delayed recognition tasks, the break between blocks was 5 minutes long, and the three blocks were all studied in the same session. In the much longer continuous-distractor recognition task, each block was studied in a separate but consecutive session. Initiation of trials within blocks was self-paced. Two practice trials preceded each task block.

Instructions for participants emphasised that both the memory and the arithmetic tasks were equally important. Participants were asked to place equal emphasis on these, and were informed that their performance on both tasks would contribute equally to their bonus. They were asked not to think of the memory task when they did the arithmetic, and vice versa. They were also asked to try to switch efficiently between tasks. To ensure compliance with the instructions to read the words and exercises aloud, participants were led to believe they were recorded throughout each session by having them speak into a microphone.

Immediate recognition: The nine words in each list were displayed sequentially for 1 second each, followed by a 1-second unfilled interstimulus interval during which the screen was blank. The screen went blank after the last word and stayed blank for a 3-second unfilled retention interval. To alert participants the test was imminent, participants heard a beep (750 ms) 1 second into the retention interval. Just before the probe word appeared, a visual mask of alphanumeric characters was presented for 250 ms, displacing any lingering representation of the last list word from iconic memory. The probe was presented in upper-case letters to prevent participants from basing their decision on perceptual similarity. Participants were asked to respond to the probe as quickly and accurately as possible during the 2 seconds it remained on the screen, by pressing one of two marked keys. The keys “1” and “2” were marked “old” and “new” and the participants responded by pressing them, respectively, with the index and middle fingers of their dominant hand, to indicate whether the probe was one of the words in the preceding list, or a new word. Participants were required to read each list word aloud, but to remain silent during probe presentation.

Distractor task: The duration of the distractor task was 15 seconds, during which participants were continuously engaged. When they solved a problem, the next problem was presented. Each problem consisted of a pair of exercises. Participants were asked to read the left exercise out loud, solve it out loud, read the right exercise out loud, solve it out loud, and then press the key corresponding to the exercise with the higher value using their non-dominant hand.

Delayed recognition: The distractor task commenced 1 second after the last word. When it ended, the screen went blank for 2 more seconds, during which the beep and the visual mask appeared following the same timing schedule as in the immediate recognition.

Continuous-distractor recognition: Participants performed the 15-second distractor task before each of the words in the list. The events following the last word were as in the delayed recognition task.

RESULTS

We obtained a recency effect in both immediate recognition and continuous-distractor recognition, but not in delayed recognition. The effect was present for both accuracy and latency. See Figure 1 for the accuracy data, and Figure 2 for the latency data.

Accuracy

Figure 1 shows that, except for a small benefit for the very first item in all three tasks, recognition accuracy, presented in terms of hit rate due to the common false alarm rate for all items, increased as a function of recency in both immediate recognition and continuous-distractor recognition, but not in delayed recognition.

We analysed participants' hit rate with a 3 (task: immediate recognition, delayed recognition, continuous-distractor recognition) $\times$ 9 (serial position) repeated measures ANOVA. The main effect of task, $F(2, 58) = 7.37$, $MSE = 0.64$, $p = .001$, partial $\eta^2 = .20$, was significant, as hit rate was higher in the immediate recognition than in the delayed recognition task, $p < .05$, and the continuous-distractor recognition task, $p < .01$, which did not differ, $p = 1.0$. The difference in hit rate reflected higher discriminability in the immediate recognition task rather than difference

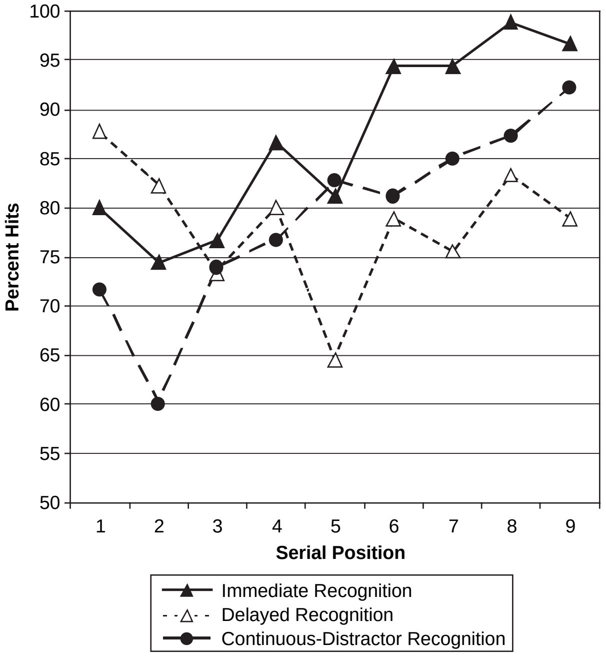

Figure 1. Accuracy (hits) as a function of serial position and task: Immediate recognition, delayed recognition, continuous-distractor recognition.

in bias (see Table 2). The main effect of serial position, $F(8, 232) = 7.11$, $MSE = 0.36$, $p < .001$, partial $\eta^2 = .20$, and the interaction, $F(16, 464) = 3.40$, $MSE = 0.16$, $p < .001$, partial $\eta^2 = .10$, were significant.

To establish that the serial-position curve was equivalent in immediate recognition and continuous-distractor recognition, but different in delayed recognition, we ran two additional ANOVAs, one comparing immediate recognition and delayed recognition, and the other comparing immediate recognition and continuous-distractor recognition. According to the single-store theories, only in the former should there be a significant interaction between task and serial position. We found that while the main effect of task and serial position were significant in both analyses—immediate recognition vs delayed recognition, task: $F(1, 29) = 9.80$, $MSE = 1.04$, $p < .01$, partial $\eta^2 = .25$, serial position: $F(8, 232) = 5.04$, $MSE = 0.22$, $p < .001$, partial $\eta^2 = .15$; immediate recognition vs continuous-distractor recognition, task: $F(1, 29) = 11.56$, $MSE = 0.88$, $p < .01$, partial $\eta^2 = .28$, serial position: $F(8, 232) = 10.15$, $MSE = 0.50$, $p < .001$, partial $\eta^2 = .26$—the interaction was only significant in the immediate recognition-delayed recognition comparison—immediate recognition vs delayed recognition: $F(8, 232) = 4.55$, $MSE = 0.17$, $p < .001$, partial $\eta^2 = .14$; immediate recognition vs continuous-distractor recognition: $F(8, 232) = 0.85$, $MSE = 0.04$, $p = .55$, partial $\eta^2 = .03$.

The accuracy data exhibited differences in primacy effects in addition to those in recency effects. Therefore, we wanted to ensure that the above dissociation between immediate recognition and continuous-distractor recognition on the one hand, and delayed recognition on the other hand, was attributed to differences in the recency effects. To this end, we examined polynomial trends in serial positions 2–9. In the immediate and the continuous-distractor task, accuracy showed a significant linear trend as a function of serial position—immediate recognition: $F(1, 29) = 32.21$, $MSE = 0.05$, $p < .001$; continuous-distractor recognition: $F(1,29) = 34.14$, $MSE = 0.05$, $p < .001$. In contrast, there was no linear trend in the delayed-recognition task, $F(1, 29) = 0.48$, $MSE = 0.03$, $p = .49$. Both immediate recognition and delayed recognition also showed a significant seventh-order trend, which we will not attempt to interpret here. No other trends reached significance.

The trend analysis was supplemented by a comparison of performance on serial positions 8–9 vs 3–4. We computed mean performance on serial positions 8–9 and serial positions 3–4, and repeated the analyses of variance reported

TABLE 2
Difference in hit rates

	Hits (percent)	*False alarms (percent)*	*Discriminability (d')*	*Bias (C)*
Immediate recognition	87	5	2.77	0.26
Delayed recognition	78	9	2.11	0.28
Continuous-distractor recognition	79	8	2.21	0.30

Discriminability and bias measures were calculated according to Brophy (1986).

above. Again, while the main effect of task and serial position were significant in both analyses—immediate recognition vs. delayed recognition, task: $F(1, 29) = 9.92$, $MSE = 0.32$, $p < .01$, partial $\eta^2 = .25$, serial position: $F(1, 29) = 10.48$, $MSE = 0.35$, $p < .01$, partial $\eta^2 = .26$; immediate recognition vs continuous-distractor recognition, task: $F(1, 29) = 17.76$, $MSE = 0.70$, $p < .001$, partial $\eta^2 = .38$, serial position: $F(1, 29) = 5.07$, $MSE = 0.16$, $p < .05$, partial $\eta^2 = .15$—the interaction was only significant in the immediate recognition-delayed recognition comparison—immediate recognition vs delayed recognition: $F(1, 29) = 7.57$, $MSE = 0.10$, $p = .01$, partial $\eta^2 = .21$; immediate recognition vs continuous-distractor recognition: $F(1, 29) = .08$, $MSE = 0.002$, $p = .78$, partial $\eta^2 = .003$.

We further computed the size of the recency effect as the difference between performance on serial positions 8–9 and serial positions 3–4. We chose this computation since, unlike serial position curves in free recall, mid-list items did not exhibit an asymptote. The size of the recency effect was significantly different from zero in the immediate recognition, $t(29) = 4.25$, $p < .001$, and continuous-distractor recognition, $t(29) = 2.67$, $p < .05$, but not in the delayed recognition, $t(29) = 1.11$, $p = .27$.

Figure 1 reveals that hit rate for probes from the fifth serial position in delayed recognition was lower than for any other probes in this task. A repeated-measures ANOVA showed that the significant effect of serial position in this task, $F(8, 240) = 2.83$, $MSE = 0.18$, $p < .05$, partial $\eta^2 = .09$, is due to the difference between serial position 5 and other serial positions (none of the other serial positions was significantly different from the others). The reason for the lower memory for this serial position is unclear, but may be due to rehearsal effects.

Correct rejection of new probes did not differ for the three tasks, $F(2, 58) = 2.05$, $MSE = 0.14$, $p = .14$, partial $\eta^2 = .07$.

Latency

Figure 2 shows that responses for the last three items were faster than for any other items in both immediate recognition and continuous-distractor recognition, but not in delayed recognition, where latency was roughly equivalent for all serial positions.

We analysed latency for correct responses only. Outliers 2.5 standard deviations above the mean for each cell were removed. Missing values (%2.5) were replaced with the linear trend at that point. We analysed participants' latency with a 3 (task: immediate recognition, delayed recognition, continuous-distractor recognition) × 3 (serial position) repeated measures ANOVA. We found significant main effect of serial position, $F(8, 232) = 2.43$, $MSE = 47923.40$, $p < .05$, partial $\eta^2 = .08$, and task, $F(2, 58) = 5.70$, $MSE = 1267765.66$, $p < .01$, partial $\eta^2 = .16$, and a significant interaction, $F(16, 464) = 1.68$, $MSE = 33597.37$, $p < .05$, partial $\eta^2 = .05$. Participants were, overall, faster to respond in the immediate recognition than in the delayed recognition task, $p < .01$, and the continuous-distractor recognition task, $p < .05$, which did not differ, $p = 1.0$. To show that the serial-position curve was equivalent in immediate recognition and continuous-distractor recognition, but different in delayed recognition, we ran two additional ANOVAs, one comparing immediate recognition and delayed recognition, and the other comparing immediate recognition and continuous-distractor recognition. According to the single-store theories, only the former should show a significant interaction. We found that while the main effect of task and serial position were significant in both analyses—immediate recognition vs delayed recognition, task: $F(1, 29) = 12.02$, $MSE = 2313574.91$, $p < .01$, partial $\eta^2 = .29$, serial position: $F(8, 232) = 3.71$, $MSE = 47609.732$, $p = .01$, partial $\eta^2 = .08$; immediate recognition-continuous vs distractor recognition, task: $F(1, 29) = 7.54$,

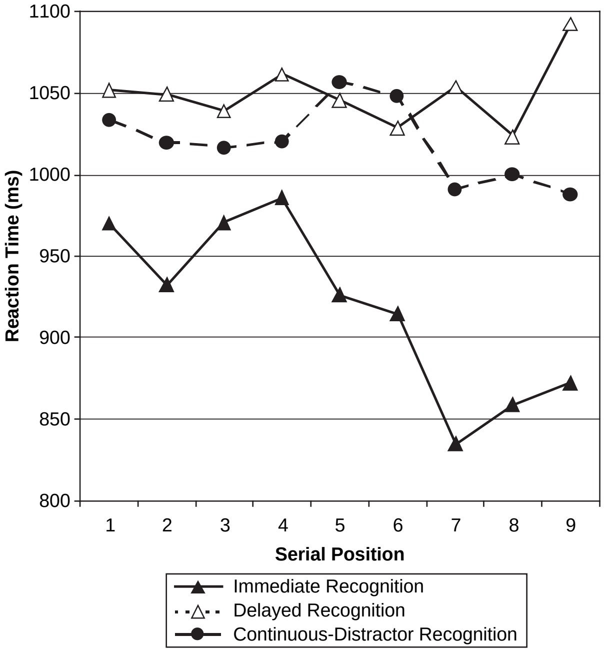

Figure 2. Latency as a function of serial position and task: Immediate recognition, delayed recognition, continuous-distractor recognition.

$MSE = 1365453.15$, $p = .01$, partial $\eta^2 = .21$, serial position: $F(8, 232) = 3.49$, $MSE = 73314.063$, $p = .001$, partial $\eta^2 = .11$—the interaction was only significant in the immediate recognition-delayed recognition comparison—immediate recognition vs delayed recognition: $F(8, 232) = 2.70$, $MSE = 50307.70$, $p < .01$, partial $\eta^2 = .08$; immediate recognition-continuous vs distractor recognition: $F(8, 232) = 1.36$, $MSE = 29589.142$, $p = .21$, partial $\eta^2 = .04$.

Latency to respond to new probes differed for the three tasks, $F(2, 58) = 10.20$, $MSE = 221084.10$, $p < .001$, partial $\eta^2 = .26$. Bonferroni-corrected pairwise comparisons showed that in accordance with the data for old probes, participants were faster to respond to new probes in immediate recognition than in delayed recognition, $p = .001$, or in continuous-distractor recognition, $p < .01$, but their performance in the latter two tasks was equivalent, $p = .50$.

Distractor-task performance

Participants could have elected to allocate fewer resources to the distractor task towards the end of the list to maximise their memory performance. To examine this possibility, we analysed participants' performance (accuracy and number of exercises attempted) on the distractor task in the continuous-distractor recognition task across list positions with two univariate ANOVAs. This analysis included the distractor task that preceded position 1, all inter-stimulus interval distractor tasks, and the retention interval distractor task. The effect of serial position was significant for number of exercises, $F(9, 261) = 6.41$, $MSE = 0.37$, $p < .001$, partial $\eta^2 = .18$, as well as for accuracy, $F(9, 261) = 4.41$, $MSE = 0.001$, $p < .001$, partial $\eta^2 = .13$. Participants attempted more exercises and were more accurate in the distractor task that preceded the list and the one that followed position 1, relative to their performance on subsequent list positions. Their performance on these subsequent positions was equivalent in terms of number of exercises, $F(7, 203) = 0.532$, $MSE = 0.01$, $p = .81$, partial $\eta^2 = .02$, and accuracy: $F(7, 203) = 0.59$, $MSE = 0.001$, $p = .76$, partial $\eta^2 = .02$.

Performance of the distractor task during the retention interval was better in delayed recognition (number of exercises: $M = 5.92$, $SD = 1.42$; accuracy: $M = \%81.34$, $SD = \%5.31$) relative to continuous-distractor recognition in terms of number of exercises, $t(29) = -6.0$, $p < .001$, as well as accuracy: $t(29) = -4.2$, $p < .001$. This difference likely arose because continuous-distractor recognition taxed more resources than delayed recognition. It cannot account for the abolished recency in delayed recognition, since recency in continuous-distractor recognition extended across multiple items rather than being limited to the very last one.

DISCUSSION

We found a recency effect in immediate recognition and continuous-distractor recognition, thereby replicating the results of Goshen-Gottstein and Talmi (2006; Talmi, 2001). Critically, a recency effect was not found in delayed recognition. These effects were robust for accuracy, with further corroboration from the latency data. In immediate recognition and continuous-distractor recognition, participants responded to late-serial-position probes faster and more accurately than to early-serial-position probes. No such pattern was found for delayed recognition. The finding of a recency effect in continuous-distractor recognition has important theoretical implications for the debate between single and dual-store theories of memory. We explore these below, relate our findings to earlier studies, and make predictions for future research.

Implications to explanations of the serial-position curve

The long-term recency effect in continuous-distractor recognition cannot rely on a short-term memory mechanism because, as evidenced by the absence of a recency effect in delayed recognition, recency items are displaced from the short-term memory buffer when participants are engaged in the distractor task. Indeed, only by including the delayed recognition condition were we able to directly conclude that the distractor was effective in clearing the putative short-term memory buffer. Indeed, the flat serial-position curve we found in delayed recognition, strikingly lacking a recency effect, attests to the distractor task's effectiveness. Therefore, the recency effects in continuous-distractor recognition performance must rely on long-term memory mechanisms.

Unlike primacy effects, it is generally agreed that the recency effect is a retrieval phenomenon. Even though the recognition test presented participants with a copy cue, the recency effect they exhibited demonstrated that they still made use of internally generated cues when making their recognition decision. This interpretation is compatible with the account of single-store theories. As was discussed above, single-store theories are dependent on participants' use of internally generated cues when they recognise single probes in order to account for the recency effect in immediate recognition tasks (e.g., Neath, 1993b; Schwartz et al., 2005). Therefore, to be consistent, single-store models must also predict a recency effect in continuous-distractor recognition tasks. This is why the absence of this effect in continuous-distractor recognition in previous studies (Bjork & Whitten, 1974; Glenberg & Kraus, 1981; Poltrock & Macleod, 1977) was problematic for single-store theories. Now we have shown that the recency effect does emerge in continuous-distractor recognition, the single-store explanation can be consistently applied to all immediate, delayed, and continuous-distractor recall and recognition tasks presented in Table 1.

In the introduction, we argued that the composite view (Davelaar et al., 2005) is neutral with regard to the continuous-distractor recognition recency findings, and is therefore also compatible with the current data set. While the composite view does not help us account for the current data any better than the more parsimonious single-store model, it may be able to account for other phenomena and dissociations not discussed here (Davelaar et al., 2005; Talmi, Grady, Goshen-Gottstein & Moscovitch, 2005; Vallar, Papagno, & Baddeley, 1991).

While our interests in the study were focused on recency effects, an interesting pattern was found in the recency-to-primacy shift in the comparison of immediate recognition and continuous-distractor recognition on the one hand, and delayed recognition on the other. The dimensional distinctiveness model (Neath, 1993a) predicts a shift from recency to primacy (reduced recency, increased primacy) with increased study–test delay, a controversial effect that is not always replicated (e.g., Kerr et al., 1999). According to the model's computational definitions, relative distinctiveness of late list items is greater in immediate relative to delayed tests, but the relative distinctiveness of early list items is greater in delayed relative to immediate tests. The model predicts that continuous-distractor performance would behave similarly to immediate performance, because the relationship between interstimulus interval and retention interval was similar in both. Therefore, the dimensional distinctiveness model predicts that relative to immediate and continuous-distractor recognition, delayed recognition should demonstrate a recency-to-primacy shift, exactly as our data show. Our findings are in line with the model's prediction with a longer list of items than previously used (Knoedler et al., 1999; Neath, 1993b). However, they cannot answer previous concerns about the reality of this effect (Kerr et al., 1999).

When we examined the latency to respond to the probe, we found that when participants had to match the probe to a long-term memory trace they were not only more accurate but also faster when they recognised probes corresponding to recency items (see Goshen-Gottstein & Talmi, 2005; Talmi, 2001, for a similar finding). Although dual-store theories, as well as the composite view, could explain the immediate recognition effect by claiming the late-list items were still in a short-term memory buffer, the inclusion of delayed recognition in the present study allowed us to conclude that speed advantage for late-serial-position probes in continuous-distractor recognition stemmed from long-term memory mechanisms. Current single-store theories do not have a ready explanation for this latency effect, but they could be extended to argue that increased relative distinctiveness, or increased number of shared contextual units, speeds up the decision process. Further research would be needed to account for the temporal dynamics in these data.

Across serial positions, latency was increased following a distractor task; namely it was longer in the delayed recognition and continuous-distractor recognition as compared to immediate recognition. This increase is likely due to the requirement to shift the mental set from the distractor to the memory task (Rogers & Monsell, 1995), a requirement absent in the immediate recognition task. This interpretation is supported by similar findings in the latency of responses to new probes.

Comparison with previous studies

The finding of a larger recency effect in continuous-distractor recognition than in delayed recognition is novel, and contrasts with earlier studies that did not obtain this effect (Bjork & Whitten, 1974; Glenberg & Kraus, 1981; Poltrock & Macleod, 1977). The most plausible reason for the difference between the current and earlier studies is that former investigations used a multiple-probe procedure. This procedure probably attenuated the effect because participants presented with a randomised test-list often responded to early-study-list-targets and lures before they were presented with late-study-list items. This amounted to an interpolated activity between the study and the test of late serial positions, which is known to reduce recency effects. In contrast, we used a single-probe recognition procedure, the more standard paradigm in immediate recognition investigations of the serial position curve.

This result replicates our previous finding of a recency effect in continuous-distractor recognition (Goshen-Gottstein and Talmi, 2005; Talmi, 2001). While our earlier study could not ascertain that the recency effect in the continuous-distractor paradigm was not the result of participants' ability to hold some of the late-list items in mind while performing the distractor task, the present study was able to rule out this interpretation. Had participants in the continuous-distractor recognition task performed better on the late list items because they used their putative short-term memory to hold those items in mind while performing the distractor task, they would have shown a recency effect in delayed recognition as well.

Predictions for future studies

Three classes of theories—distinctiveness-based single-store theories, context-based single-store theories, and the composite view—could account for the present findings. Our findings now allow us to contrast their predictions for immediate and continuous-distractor recall and recognition. Distinctiveness-based single-store theories would predict equal recency effects in all these tasks, because the computation of relative distinctiveness is scale and test invariant. The composite view would similarly predict that recency would be of similar magnitude in recall and recognition, but does not require that the recency effect would be equivalent in immediate and continuous distractor tasks. Similarly to distinctiveness-based theories, context-based theories would predict equal recency in immediate recognition and continuous-distractor tasks, since both should use contextual cues to the same degree. In contrast to the other two models, because contextual information plays a larger role in recall than in recognition, context-based single-store theories would predict an attenuated recency effect in recognition relative to recall. Future research is needed to examine these predictions.

To conclude, overcoming a previous confound, our findings extend the long-term recency effect to recognition memory. This finding follows the prediction of single-store models and supports these theories over dual-store models. It remains to be seen whether single-process models can provide accurate quantitative fits to the long-term recency effect in recognition, or whether we need to invoke additional mechanisms as in the composite model.

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