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Long-term recency in anterograde amnesia

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Abstract

Anterograde amnesia is defined as impaired long-term memory (LTM) despite preserved short-term memory (STM). A pattern that supports this understanding of amnesia is that when people with amnesia recall a list of studied words their memory for early study-list words - thought to be retrieved from LTM - is impaired, but their memory for the last few studied words - thought to be retrieved from STM - is intact. Here we asked whether people with amnesia will also exhibit a memory advantage for the most recent items they encoded when they are forced to retrieve them from LTM. This effect, called long-term recency, is a core prediction of both single and dual store models of memory but had not been demonstrated conclusively in amnesia. To examine this question we inserted a distractor task after each list item, including the last item, and then asked people with amnesia and matched controls to recall the words freely. Patients exhibited immediate and long-term recency effects, suggesting that the argument against early dual-store models of memory, derived from the long-term recency effect in neurologically intact participants, holds for this patient population. Interestingly, the impairment patients exhibited was not apparent when analysis was confined to the first recalled item in every list. We discuss the implications of this finding for single and dual-store models of memory and amnesia and for rehabilitation.

1. Introduction

Anterograde amnesia is defined as an impairment of memory retrieval from a long-term memory store accompanied by intact retrieval from a short-term memory store or working memory (Baddeley & Warrington, 1970; Scoville & Milner, 1957; Strauss & Spreen, 1991), a definition expressed in many modern textbooks (Banich, 2011; Kolb & Whishaw, 2010). This view of amnesia assumes a dual-store model of memory (Jonides et al., 2008), and provocatively, even Crowder (Crowder, 1982), who argues against dual-store models, pointed out that his own textbook (Crowder, 1976) expressed this view. This definition has persisted despite an ongoing debate between dual-store and single-store models on explaining healthy memory behavior (Brown, Della, Foster, & Vousden, 2007; Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Kahana, Sederberg, & Howard, 2008; Polyn, Norman, & Kahana, 2009; Sederberg, Howard, & Kahana, 2008; Usher, Davelaar, Haarmann, & Goshen-Gottstein, 2008). Here we focus on two areas of contention in the account that both of these models provide for amnesia.

An effect termed long-term recency, found in healthy participants, was a major driving force behind the debate between dual and single store models, and was critical to their refinement. A core prediction of both single-store models and a new breed of dual-store models, which had so far not been conclusively demonstrated, is that the same effect will be preserved in amnesia. Our first aim was to demonstrate that this is the case. We then focus on the first item that participants recalled, henceforth ‘first recall’ (Hogan, 1975; Howard & Kahana, 1999b; Laming, 1999) because the two models give different accounts of first recall relative to the recall of further items. Our second aim was to show that analysis of first recall provides important clues about the specific impairment in amnesia and helps inform the debate between dual and single store models.

The strongest and most direct support of early, “classical” dual-store models of amnesia was the finding that in immediate free recall (IFR). This task presents participants with a list of words and they are immediately asked to recall as many words as they can, regardless of the order of presentation. People with amnesia exhibit an intact recency effect— advantage in recalling late list items relative to midlist items— in this task, but reduced probability of recalling items from earlier in the list (Baddeley & Warrington, 1970; Brooks & Baddeley, 2011; Brown, Rosenbaum, Lewis, & Rourke, 1980; Capitani, Della, Logie, & Spinnler, 1992; Moscovitch, 1982a; Moscovitch, 1982b). Support for early dual-store models dwindled, however, when three variants of free recall tasks were compared in healthy participants. First, the recency effect is observed in IFR (‘immediate recency effect’,(Murdock, 1962). Second, when a distracting task is added at the end of the list, prior to the recall test (delayed free recall, DFR), the recency effect is attenuated or abolished. Third, when a distracting task is interpolated after each word in the study list, a procedure known as continuous-distractor free recall (CDFR), the recency effect is observed (Baddeley & Hitch, 1977; Bjork & Whitten, 1974; Postman & Phillips, 1965). The presence of recency in IFR and its relative absence in DFR is what motivated early dual-store models (Atkinson & Shiffrin, 1968; Glanzer & Kunitz, 1966; Postman & Phillips, 1965) because it was compatible with the notion that final list items were simply and effortlessly retrieved from a short-term store whereas retrieval of items from the long-term store was more effortful. A central assumption of early dual-store models was that retrieval from the long-term store is recency-less, explaining the near-flatness of the serial position curve in DFR. These models also agreed that all retrieval in DFR and CDFR came from the long-term store, because of the end-of-list distractor common to both paradigms. Therefore, early dual store models predicted that the serial position curve in CDFR should also be flat, exhibiting no recency. Thus, the surprising return of recency in CDFR was termed "long-term recency" to make the point that if dual-store models were correct, this recency effect must have been due to retrieval from the long-term store. Long-term recency, which has been replicated many times in healthy participants, was held as evidence against early dual-store models (Baddeley & Hitch, 1977; Carlesimo, Marfia, Loasses, & Caltagirone, 1996; Crowder, 1993; Crowder, 1982; Greene, 1986; Talmi & Goshen-Gottstein, 2006; Waugh & Norman, 1965).

In contrast, long-term recency was a natural prediction of interference-theory models, which posit a single memory store and can explain the pattern of recency across IFR, DFR and CDFR. These models assume that in free recall, all studied items compete to be retrieved. Competition is related to the recency of the item. Thus, the ratio of recencies between a pair of items determines how much they compete with one another (Bjork & Whitten, 1974). Known as the *ratio rule*, this property makes interference-theory-based models scale-invariant, in contrast to the early dual-store models, which assumed that memory operates differently at two different time scales. Despite the prominence of the definition of amnesia as a disorder of long-term memory accompanied by intact short-term memory, there are accounts of the performance of people with amnesia in free recall that do not depend on the existence of two memory stores, and are thus consistent with single-store models (Brown, Neath, & Chater, 2007; Carlesimo et al., 1996; Crowder, 1982; Sederberg et al., 2008).

The finding of long-term recency in healthy participants promoted a refinement of dual-store models. Davelaar et al (2005) proposed a ‘hybrid’ dual-store model that accommodates the long-term recency effect by abandoning the recency-less LTM and instead assuming that LTM itself functions as an interference-theory-based model would predict. The main difference between single-store models and this hybrid dual-store model is that the latter additionally includes a separate short-term memory store. Notably, because both single-store models and hybrid dual-store models use interference theory to account for performance in DFR and CDFR, both predict that long-term recency would be observed in amnesia. Because this effect was such a critical finding in the development of memory models, we wished to test whether this prediction holds true.

If long-term recency could be observed in amnesia, then one could conclude that the spared long-term memory in amnesia obeys some of the same rules as in neurologically intact controls, a result which, as we suggest below, may have useful implications for rehabilitation. What made this demonstration particularly challenging was that in amnesia performance with a single end-of-list distractor in DFR is already at such a low level (Carlesimo et al., 1996) that one might imagine the continuous-distractor procedure in CDFR would simply push the already-floor performance further into the ground. It was quite possible, therefore, that the CDFR procedure would be so difficult for people with amnesia that long-term recency would never be observed.

One study, by Carlesimo et al. (1996), sought to test whether long-term recency could be observed in people with amnesia. In IFR they used the standard word-list learning procedure and reported that the patients recalled as many words as controls from the final portion of the list— in line with previous work (Baddeley & Warrington, 1970; Brooks &

Baddeley, 2011; Brown et al., 1980; Capitani et al., 1992; Moscovitch, 1982a; Moscovitch, 1982b) and the classical dual store model. In CDFR, in order to ensure above-floor performance, participants were then given a list of words as anagrams to solve, with an arithmetic task (distractor) following each anagram, including the last item. The unscrambled words were the target materials for subsequent recall. People with amnesia showed an overall depressed serial position curve in this paradigm, but exhibited a small recency effect. Although their immediate recency was indistinguishable from that of controls, their CDFR performance across all serial positions did not reach the recall level of control participants, which the authors interpreted as a deficient long-term recency effect. In scrutinizing their methodology, however, we observed that their study lacked the DFR condition. It is therefore possible that the arithmetic distractor they used, in conjunction with the anagram method which, as intended, may have made the task easier overall, was insufficient to clear out the short-term store. In that case, the recency effect obtained may have been based on retrieval from the short-term store and was not a long-term recency effect at all. The inclusion of DFR in the experimental procedure is necessary to test this possibility: if the DFR condition also exhibited a recency effect, the recency effect in CDFR would not qualify as a long-term recency effect. On the other hand, if DFR showed a flattened recency effect that then returned in CDFR (particularly if recall of the terminal list item were more probable in CDFR than in DFR), that would be strong evidence for long-term recency. Furthermore, the theoretically important comparison between the recency effect in IFR and CDFR in the Carlesimo et al. (1996) study was confounded by the use of completely different methodologies in the two tasks. For example, controls may have rehearsed more than patients in CDFR (Brown et al., 2007) so that the recency effect they exhibited in that task may have been more contaminated by STM than that exhibited by the patients. To test directly whether a long-term recency effect could be observed in amnesia and examine its magnitude we applied the full set of conditions (IFR, DFR and CDFR) to both people with amnesia and neurologically intact controls, using the same procedure across conditions and groups.

Beyond demonstrating the mere presence of the long-term recency effect in amnesia, we also were interested in establishing whether its magnitude is equivalent in patients and controls. Free recall studies typically consider the entire free recall output, and report average recall per serial position across study lists without considering the many factors that can influence the specific sequence of stimuli that participants recall freely (Howard & Kahana, 2002; Tulving, 1966). Models of free recall assume that retrieval operates differently for the first item that is recalled than for subsequent recalls— dating back even to the early, classical dual-store model, such as Search of Associative Memory (SAM). SAM assumes that retrieval from long-term memory starts with the participant cueing memory with list context, but once the first item is retrieved, that item is used as the cue for the next response (e.g., Atkinson & Shiffrin, 1968). Thus, a measure that could help us isolate mechanisms of memory impairment in amnesia is the probability of first recall— the serial position curve based exclusively on the first recalled item on each list, across all of the lists presented to the participant in the experimental session (Hogan, 1975; Howard & Kahana, 1999a; Laming, 1999). The critical issue was whether the recency effect would already be reduced on the first recall, or emerges later in the sequence of responses. If the probability of first recall is identical for Controls and amnesics this would constrain accounts of amnesia to effects that emerge later in output.

Finally, we note that the question of whether or not people with amnesia exhibit a long-term recency effect is not only of theoretical interest. Currently, in accordance with the classical, early dual store model definition of amnesia, patients are thought not to be able to remember any information beyond what they can retain in short-term memory. Although clinical observations show that patients do sporadically report such information, and free recall intrusions from previous list have also been documented in the research literature (Warrington & Weiskrantz, 1968), these reports are not thought to be governed by any known rules and are therefore dismissed. A demonstration of a long-term recency effect in amnesia would provide strong support to the operation of the ratio rule even when long-term memory is severely impaired, and rehabilitation scientists could build on this rule to help patients and their caretakers.

To emphasize the clinical relevance of our findings it was important that we demonstrate the ecological validity of the long-term recency effect. For this purpose we designed an incidental song-recall task. Participants listened to one song after each free-recall period (following each of the study lists) and were asked to -recall the songs at the end of the testing session. The song-recall task can be viewed as a form of continuous-distractor free recall procedure, in which the word-list task takes on the role of the distractor. If participants with amnesia exhibit long-term recency in CDFR, they should also recall more of the songs they studied late in the course of the experiment relative to those they studied in the beginning of the session.

2. Material and methods

2.1 Participants

13 patients and 15 healthy control subjects participated in this study. Patients and controls were matched on age ($t<1$), years of education ($t<1$), digit span forward ($t<1$) or backward [$t(24)=1.21$, $p>.10$] and premorbid intelligence as assessed by the Wechsler Adult Test of Reading (WTAR, $t<1$), see Table 1. 12 of the patients were referred to the Memory Link program in Baycrest, Toronto, Canada because of impaired memory caused by a variety of traumatic disorders such as ruptured aneurysm and encephalitis. Patient KC was originally referred to MM in 1983 following a closed head injury (Rosenbaum et al., 2005) and has volunteered in our studies since then.. We excluded data from three patients who were impaired on both phonemic fluency and the Wisconsin Card Sorting Test, both of which are tests sensitive to frontal lobe damage. An additional patient was excluded from all further analysis because she recalled more midlist than recency words in IFR, unlike any of the other patients or controls. As shown in Table 2, all the 9 patients included in our final sample had severely impaired performance on tests of long term memory as assessed by CVLT and BVT, accompanied by preserved digit span, intelligence and normal function on at least one of the tests sensitive to frontal damage. Thus, although the etiologies leading to amnesia differ among the patients, the functional consequences are the same with respect to loss of LTM but relatively preserved STM as these functions are defined on standard tests. This functional impairment is the starting point, and focus, of ours study.

Tables 1 and 2 about here

Control participants were recruited from the University of Toronto and the Rotman Research Institute volunteer pool. The study received the approval of the Toronto Academic Health Sciences Network ethics review board.

2.2 Materials

2.2.1 Word stimuli. Word lists included 9 words. Six of the words for each one of the three lists in each one of the three experimental tasks (Immediate Free Recall - IFR, Delayed Free recall - DFR, and Continuous Distractor Free Recall - CDFR) were randomly sampled without replacement for each participant from the same pool of 78 words. In addition, to these six words, three 'target' words in each list were sampled without replacement from a separate pool of 27 words and placed randomly in serial positions 1, 5, and 9. The 3-letter stem of target words had between 4 and 9 accessible completions (M=5.78, SD=1.7%) and the average probability of each word to be given as a first response to the stem ranged from 2% to 9.3% (M=4.1%, SD=2.2% according to published norms (Ryan, Ostergaard, Norton, & Johnson, 2001). None of the target words had the same stem as another word in the experiment. All experimental words were nouns, had 5-6 letters, mean frequency of 41.62, SD=54.68 (Kucera & Francis, 1967), mean concreteness of 553, SD=67.37 (Wilson, 1988), and all were neutral in valence. To reduce proactive interference, words for practice trials were all proper names, sampled from a pool of 30 male and female first names. Words were presented in lowercase, black 72-point times-new-roman font on a yellow background.

2.2.2 Distractor task stimuli. The stimuli for the distractor task were simple yet cognitively demanding arithmetic problems. Each included three randomly sampled single digits and a solution which could be correct or incorrect. Two of the digits had values between 1-5 and one had values between 1-9. Incorrect solutions were larger or smaller than the correct one by 1 (for example, 9+4+2 =16 or 3+8+1=12). The problems were presented on a gray background in the center of to the left or the right of the center of a gray screen, in black 28-point times-new-roman font.

2.2.3 Song excerpts. All songs used in the song-recall task were highly familiar, uplifting, popular American songs, such as ‘Rock around the clock’ or ‘Singing in the rain’. To increase the chances that most participants, even those with retrograde amnesia, would be familiar with most of the songs, we selected songs which were mostly released in the fifties and sixties; the most recent song used was American Pie, released in 1971. One-minute excerpts from each song, which included the most familiar part (e.g. the chorus), were converted to 22050 samples, 8-bit stereo files. Song order was randomized for each participant.

2.3 Procedure

Prior to the experiment itself, participants received initial practice which included studying and recalling three 4-word lists, and performing the distractor task three times. Following initial practice, all participants were able to perform these tasks adequately. Each task began with instructions and one practice list, and included three 9-word experimental lists. Participants were reminded of the instructions before each experimental list. Task order was counterbalanced. A five-minute break followed each task. During the first break participants completed the WTAR; there was no task during the second break;

following the final task they were administered the digit span task, and were then asked to recall the songs.

2.3.1 Immediate free recall (IFR). Words were presented for 3 seconds each. The orienting task for encoding required participants to rate each word as either 'pleasant' or 'unpleasant'. They rated the words by pressing one of two marked keys on a computer keyboard; the rest of the keyboard was covered with cardboard in order to make it easier for patients to switch back to the orienting task in CDFR A blank inter-stimulus interval (ISI) of 500 ms followed each word. The instructions 'Recall words' were presented after the final ISI and participants were given 45 seconds to recall studied words in any order.

2.3.2 Cued recall. Immediately following the free recall test, participants were given instructions for a cued recall test. This test provides more support during retrieval than free recall and was included in case patients' free recall memory was at floor. The instructions (following (Mayes, Pickering, & Fairbairn, 1987) encouraged participants to first think back about the studied list and attempt to retrieve a studied word, but if they could recall no appropriate completion, to complete the stem with the first word that came to mind. The cued recall test consisted of a presentation of the stems for each one of the three target words (serial positions 1, 5 and 9) in a random order. Participants verbally completed each presented stem before the next stem appeared. The cued recall test also allowed even the most densely amnesic participants to experience some success in retrieving studied words and helped motivate them during the course of this challenging experiment.

2.3.3 Song encoding. Immediately following the free recall test, participants were instructed to relax and listen to a single song excerpt. They then answered the following questions about it: (1) Is the song familiar to you? (2) What is the name of the song? (3) Do you know all, some, or none of the words? (4) Can you hum all, some, or none of the tune? All participants enjoyed the song task and experienced success in it, which helped motivate those who found recalling the words particularly challenging.

2.3.4 Delayed free recall (DFR). The procedure was almost identical to IFR, except that following the last ISI participants performed the distractor task for 30 seconds.

2.3.5 Distractor task. The computer monitor changed color to grey when the task began. A single arithmetic problem was presented, and participants read it out loud, and say 'yes' if the solution was correct, and 'no' if it was incorrect. The experimenter keyed in their response, which triggered the next problem.

2.3.6 Continuous-distractor free recall (CDFR). The procedure was almost identical to that of the IFR task, but instead of the blank ISI which followed each word, participants performed the arithmetic task for 15 seconds. They also performed the distractor task for 15 seconds once before the first word, and for 30 seconds after the last studied word.

2.3.7 Adapting the recall task to people with amnesia. Task switching between word study and the distractor task was more difficult for patients than controls, because they did not always remember the complete set of instructions. When patients failed to rate a word, or did not immediately begin reading the arithmetic problems, the experimenter gave short reminders, either pointing at the keyboard or at the screen, or providing short verbal cues ('read the exercise', 'rate the word'). Following the practice list, patients were able to perform the tasks adequately with minimum reminders. The necessity of these reminders for patients but not controls was the only difference in procedure between the two groups.

3. Results

3.1 Free recall of words.

Percent recall was computed across the three free recall tests in each condition, separately for each serial position. We used the Greenhouse-Geisser correction for violations of sphericity whenever necessary and analyzed polynomial trends to the fourth order.

Figure 1 plots the data in a similar manner as Carlesimo et al. (1996) did. This figure shows that all participants exhibited a recency effect in IFR (Figure 1a) and CDFR (Figure 1c), but not in DFR (Figure 1b), the condition that was absent in Carlesimo et al.'s study. Although patients exhibited a recency effect (greater recall of the end-of-list items than earlier items) in both IFR and CDFR, the number of words they recalled of the late portion of the study list equaled that of controls only in IFR, not in CDFR, where their memory (probability of recall) was depressed for all serial positions relative to controls, replicating Carlesimo et al. (1996). Figure 2 shows that the DFR condition is critical for the interpretation of the data with respect to the long-term recency effect: patients (Figure 2b) as well as controls (Figure 2a) show a long-term recency effect— that is, probability of recall of the last item that is greater in CDFR than in DFR.

Free recall data were analyzed with a Task (IFR, DFR, CDFR) x Serial position (1–9) repeated-measures ANOVAs with Group (patients, controls) as a between-subjects factor. The main effects of Task [$F(2,44)=45.02$, $p<.001$, partial $\eta^2=.67$] and Serial Position

[F(8, 176)=9.07, $p<.001$, partial $\eta^2=.29$] were significant, as well as the interaction between them [F(16,352)=5.98, $p<.001$, partial $\eta^2=.21$]. The main effect of Group [F(1,22)=30.04, $p<.001$, partial $\eta^2=.58$] was significant, and it interacted with Serial Position [F(8,176)=2.24, $p<.05$, partial $\eta^2=.09$]. The three-way interaction did not reach significance [F(16,352)=1.38, $p>.10$, partial $\eta^2 = .06$]. To increase the power of this analysis we averaged serial positions 7-8-9 (recency), 4-5-6 (midlist), and 1-2-3 (primacy) and ran the analysis again. The same pattern was obtained, but this time the 3-way interaction was significant [F(4,88)=3.14, $p<.05$, partial $\eta^2 = .12$].

Figure 1 about here

We explored the 2-way interaction between Task and Serial Position by analyzing each task separately, using Serial Position as a within-subject factor and Group as a between-subject factor. In IFR there was a significant effect of Serial Position [F(8,176)=15.86, $p<.001$, partial $\eta^2=.42$], which exhibited a linear [F(1,22)=11.60, $p<.01$, partial $\eta^2=.34$] and a more pronounced quadratic [F(1,22)=98.20, $p<.001$, partial $\eta^2=.82$] trend, consistent with the presence of primacy and recency effects. The effect of Group was significant [F(1,22)=13.07, $p<.01$, partial $\eta^2=.37$] and Group interacted with Serial Position [F(8,176)=3.25, $p<.01$, partial $\eta^2=.13$]. To explore this interaction we carried out a series of Bonferroni-corrected one-tailed t-tests on recall from primacy, midlist and recency positions, computed as described above. These revealed that this interaction was due to the fact that relative to patients, controls recalled more primacy [t(22)=4.35, $p=.001$] and midlist [t(22)=2.69, $p<.05$] items, but there was no significant difference between the groups in recall of recency items ($t<1$). As expected, both controls [$t(14)=5.12$ $p<001$] and patients [$t(8)=6.61$, $p<.001$] recalled more recency than midlist items. In CDFR Serial Position had a significant effect on probability of recall [$F(8,176)=1.99$, $p=.05$, partial $\eta^2=.08$], an effect which exhibited a quadratic trend [$F(1,22)=6.50$, $p<.05$, partial $\eta^2=.23$]. The main effect of Group was significant [$F(1,22)=20.23$, $p<.001$, partial $\eta^2=.48$] but Group did not interact with Serial Position [$F<1$]. Recency items were recalled more often than midlist items when both groups were considered together [$t(23)=2.53$, $p<05$, one-tailed]. Although the interaction with Group was not significant, for completion we report that one-tailed t-tests confirmed that this effect remained significant when each group was examined separately [controls: $t(14)=1.93$, $p=.07$; patients: $t(8)=2.29$, $p=.05$]. Serial Position did not have a significant effect on DFR, [$F(8,176)=1.07$, $p>.10$, partial $\eta^2=.05$]. The main effect of Group was significant [$F(1,22)=30.86$, $p<.001$, partial $\eta^2=.58$] but Group did not interact significantly with Serial Position [$F<1$].

Figure 2 about here

3.2 Probability of first recall.

To determine whether impairments in amnesia are present at the very start of retrieval, or unfold over the course of successive retrievals, we analyzed the probability of first recall. For each one of the three experimental lists, participants received a score of 1 for each serial position on which they recalled a word, and 0 if they recalled nothing or if the first word they recalled was an intrusion, yielding a score of 0–3 for each serial position in each task. Figure 3 shows that patients and controls exhibited an equivalent propensity to recall the most recent list item in IFR (Figure 3a) and CDFR (Figure 3c), but that relative to controls, patients recalled fewer position 1 words in all three tasks. We analyzed the probability of recalling a word from position 1, 5 and 9 with a 3 (task) by 3 (Serial position) repeated-measures ANOVA. There were significant main effects of task [$F(2,44)=4.69$, $p<.05$, partial $\eta^2=.18$], serial position [$F(2,44)=15.14$, $p<.001$, partial $\eta^2=.41$], and Group [$F(1,22)=9.32$, $p<.01$, partial $\eta^2=.30$]. There were significant interactions between Task and Serial Position [$F(4,88)=1.83$, $p<.05$, partial $\eta^2=.14$] and Group and Task [$F(2,44)=4.69$, $p<05$, partial $\eta^2=.17$]. To unpack the interaction of Task and Serial Position each task was analyzed separately with Serial Position as a within-subject factor and Group as a between-subject factor.

There was a significant main effect of Serial Position on IFR [$F(2,44)=6.21$, $p<.01$, partial $\eta^2=.22$], which exhibited a quadratic trend [$F(1,21)=46.87$, $p<.001$, partial $\eta^2=.68$]. The main effect of Group was significant [$F(1,22)=6.76$, $p<.05$, partial $\eta^2=.64$] and Group interacted with Serial Position [$F(2,44)=4.27$, $p<.05$]. Bonferroni-corrected t-tests showed that this interaction was due to the fact that controls recalled more position 1 items [$t(22)=2.93$, $p<.01$] but there was no difference between the groups in recall of position 9 ($t<1$) or position 5 [$t(22)=1.10$, $p>.10$] items. In CDFR the only significant effect was that of Serial Position [$F(2,44)=4.13$, $p<.05$], which exhibited a quadratic trend [$F(1,22)=5.25$, $p<.05$]. Because of the importance of the comparison between the groups in recall of position 9 we report this post-hoc comparison despite the absence of a significant interaction [$t<1$]. In DFR the only significant effect was the main effect of Group [$F(1,22)=4.85$, $p<.05$].

Figure 3 about here

3.3 Free recall of songs.

Participants received a score of 1 when they recalled a song, and 0 when they did not. Figure 4 shows primacy and recency effects in this task for both patients and controls. Song recall was analyzed with a repeated-measures ANOVA, using Group as a between-subject factor. The results replicated the results from CDFR. The main effect of serial position was significant [$F(11,242)=2.74$, $p<.01$, partial $\eta^2=.11$], and exhibited linear [$F(1,22)=20.11$, $p<.001$, partial $\eta^2=.48$] and quadratic [$F(1,22)=7.22$, $p<.05$, partial $\eta^2=.25$] trends consistent with the presence of both recency and primacy effects. Patients recalled fewer songs than controls [$F(1,22)=10.85$, $p<.01$, partial $\eta^2=.33$] but Group did not interact with Serial Position, $F<1$.

Figure 4 about here

3.4 Cued recall of words.

These data were analyzed using a 3 (Serial Position: 1, 5 ,9) by Task (IFR, DFR, CDFR) repeated-measures ANOVA with group as the between-subject factor. The main effects of Task [$F(2,44)=10.85$, $p<.001$, partial $\eta^2=.33$] was due to participants recalling more words in the IFR than in the DFR, and in DFR than CDFR. Patients recalled fewer words than controls [$F(1,22)=6.43$, $p<.05$, partial $\eta^2=.23$]. No other effects were significant, possibly due to insufficient power. As no serial position effects were observed, data from this task will not be discussed further.

3.5 Distractor task.

The effect of Task (DFR, CDFR) on the number of exercises attempted and on solution accuracy during the distractor task was analyzed with two repeated measures ANOVAs with Group as a between-subject factor. The results indicate that patients found the distractor task more difficult than controls in both DFR and CDFR. Patients attempted to solve fewer exercises than controls $F(1,22)=5.44$, $p<.05$, partial $\eta^2=.20$, and their accuracy was overall lower than that of controls, $F(1,22)=5.21$, $p<.05$, partial $\eta^2=.19$. All participants attempted more exercises in CDFR than DFR task [$F(1,22)=45.05$, $p<.001$, partial $\eta^2=.67$; the interaction with Group was non-significant, $F(1,22)=3.68$, $p=.07$]. Accuracy was higher in DFR [$F(1,22)=19.41$, $p<.001$, partial $\eta^2=.47$].

4. Discussion

Our chief finding was evidence of short-term and long-term recency effects in both neurologically intact participants and participants with amnesia. When the full serial position curve (summing over all responses) was considered patients exhibited reduced probability of recall for all but the recency portion of the IFR condition. The relative advantage in recalling late list items was equivalent in patients and controls in CDFR. An analogous finding to the long-term recency in the CDFR task was obtained for recall of interspersed songs.

We extend previous results by analyzing the very first item that participants recalled (probability of first recall). Strikingly, the qualitative difference in memory between patients and controls across almost all conditions, which was apparent when all recall output was considered, was almost entirely eliminated when analysis was limited to the first recall attempt. The only exception was a one-item primacy effect in IFR which was greater in controls, likely due people with amnesia rehearsing less than controls (Brown et al., 2007; Brown et al., 1980). Probability of recall of the last list item was greater in CDFR than in DFR for both groups, consistent with a return of the recency effect in CDFR. The most important aspect of this analysis for our purpose is that patients recalled the last item as much as controls in both IFR and CDFR. Essentially, the impairment patients exhibited in recalling late serial positions in CDFR was not present at the start of recall but emerged later in retrieval.

As a consequence of our additional DFR condition we can also be certain that, if dual-store models are correct, in our study both groups of participants must have retrieved the recency items in CDFR from long-term memory. This finding attests to the effectiveness of the distractor task in eliminating participants' ability to short-term memory resources to aid recall. One potential caveat for the comparison between patients and controls in DFR and CDFR was that patients performed more poorly on the distractor task than controls. This may have influenced the amount of interference the two groups have experienced, but from these data we cannot tell whether patients suffered more interference (because they found the distractor task more difficult) or less interference (because they solved fewer arithmetic problems). Notably, the time both patients and controls invested in the distractor task was equivalent.

We could not obtain proper structural neuroimaging data on many of the patients. For those for whom such data were available, the lesions were not circumscribed to a single structure such as the hippocampus, consistent with the varied etiologies of their disorder. Our findings, therefore, speak only to the functional consequences of amnesia and not to its structural correlates. The procedure we developed, however, can be used in the future to study a larger sample of patients whose lesions are well documented and determine, thereby, whether the pattern of preserved and deficient performance is associated with any particular lesion or is common across all amnesic syndromes.

4.1 Theoretical implications.

The finding of long-term recency in amnesia extends previous findings in healthy participants and current control participants, and further discredits classical dual-store models of memory, which cannot explain this effect. While classical dual store models of memory are no longer accepted, Davelaar et al. (2005) proposed a modern, 'hybrid' dual-store account of amnesia. In their view, long-term recency (the recency effect in CDFR) and immediate recency (the recency effect in IFR) just happen to resemble one another, but derive from different causes. They suggested that immediate recency is due to an advantage items have in recall if they are present within the short-term store at time of test, but in contrast, long-term recency is explained much like the interference theory account (i.e., by the ratio rule). Because both this model and single-store models of memory rely on interference mechanisms to account for the pattern of retrieval from long-term memory, this effect alone cannot decide between them. Instead, our finding of long-term recency in both healthy participants and amnesic patients conforms to a core prediction of interference-based accounts of LTM, and as such supports both single-store and hybrid dual-store accounts of amnesia, as long as retrieval from long-term memory (whether or not distinct from short-term memory) is at least partly preserved. When it is, LTM obeys, at least in part, similar rules in amnesia as in healthy memory.

The comparison between the recall of amnesic patients and healthy controls in IFR and CDFR appears to hold more promise as a test between these two classes of models. Carlesimo et al. (1996) suggested that their finding - that people with amnesia recall fewer recency items in CDFR than controls but as many recency items as controls in IFR – supported the hybrid model. Our findings are consistent with those of Carlesimo and colleagues (1996) for the conditions common to both. Crucially, because we included a DFR condition and used the same procedure across IFR, DFR and CDFR we can be more confident than Carlesimo et al. (1996) in comparing IFR and CDFR across participants groups. Hybrid dual-store models of memory provide a straightforward explanation for the finding that when the full serial position curve was considered patients exhibited reduced probability of recall for all but the recency portion of the IFR condition. According to Davelaar et al.'s (2005) account patients' recall in CDFR was depressed over all serial positions because of their impaired long-term memory (but with a recency effect because long-term memory is subject to the ratio rule), but in IFR they can utilize their intact short-term memory store to recall late list items as effectively as controls. Yet importantly, patients' performance on IFR and CDFR here and in Carelesimo et al.'s (2005) study does not contradict the predictions of single-store models of memory.

Measuring the probability of first recall offers an interesting test for all models. The probability of first recall is arguably a cleaner measure of memory because it avoids output-order interference effects. Most models assume that the item that is recalled first is likely the strongest, namely the one best able to compete for retrieval resources with other items. Our findings show that at the end of the IFR and CDFR lists the very last studied item was equally accessible for both patients and controls regardless of the fact that in CDFR an effective 30-second distractor interval preceded the cue to begin recall. According to Davelaar et al.'s model, however, we should have observed a reduced probability of recall in amnesia across the *entire* recall output, including the first response per list. Our finding of intact recency in both IFR and CDFR in the probability of first recall measure thus provide a challenge for this account. We note, however, that we may not have had sufficient power to detect such subtle differences.

Interestingly, while our analysis of the probability of first recall challenge dual-store models of memory, it helps single-store models account for the same data. Sederberg et al. (2008) proposed that the single-store, interference-theory model, called the Temporal Context Model (Howard & Kahana, 1999) could provide another explanation than that of Davelaar et al. for the differences in healthy performance on CDFR versus IFR. The model uses a specific representation of context as a retrieval cue. It also includes the assumption that when an item is retrieved, its context is retrieved along with it, and this retrieved context then becomes part of the next retrieval cue. Thus, at the start of free recall, the only cue available is the current context. Current context would be quite similar to the context learned along with list items in IFR, slightly less similar to studied items in CDFR, and least similar to studied list items in DFR (all based on the ratio-rule-like assumption that the distractor task simply acts to accelerate contextual drift). They then proposed that amnesia might be understood as impaired learning of new context-item associations, with an intact ability to use current context as a retrieval cue. This kind of mechanism might explain the effects we observed: If cueing with current list context is intact, then this should produce intact retrieval of the most recent items in IFR, and an impairment for all earlier serial positions and for all serial positions in both DFR and CDFR, since those conditions rely more on the use of retrieved context (via item-context associations) as a retrieval cue. However, for the very first recall (corresponding to our probability of first recall measure), current context is the only retrieval route available to controls as well as amnesics, so differences should not yet be apparent. For all subsequent output positions, however, retrieved context would be expected to enhance control participants' ability to retrieve additional items, a mechanism unavailable to amnesics. Although the Sederberg et al. model explains immediate and long-term recency, as well as the difference between groups in absolute recall outputs in IFR and CDFR and the similarity between the groups in probability of first recall using one memory store, it is not necessarily more parsimonous than Davelaar et al's model. The important point is that the probability of first recall data could be used as a clue to constrain the possible mechanisms in both single and dual-store models.

4.2. Differences in the primacy effect.

One feature of our data was that amnesic people had impaired primacy effects (i.e., a reduced advantage in memory for the first few presented items). Brown et al. (2007) argued that a reduced primacy effect in IFR in amnesia could be explained as the amnesic failing to rehearse during presentation of the list. They successfully fit their single-store model based on interference theory, Scale-Independent Memory, Perception and Learning (Brown, Neath & Chater, 2007) to serial position curves based on the time of last presentation or rehearsal, known as a "functional serial position curve"(Brodie, 1975; Brodie & Murdock, 1977; Hunt & Worthen, 2006). Brown et al.'s argument was that if a rehearsal represents an encoding trial similar to a study trial, then plotting serial position curves based on time of last presentation/rehearsal should control for differences in rehearsal between groups. They demonstrated both that the model could fit the amnesic data well and that the impairment was no longer apparent in the functional serial position curves. Thus, rehearsal during presentation of the list could account for impairments of primacy effects in amnesia, a question not directly considered here because it was not part of the conventional argument between dual- and single-store models.

4.3 Song recall and clinical implications

An analogous finding to the long-term recency in the CDFR task was obtained for recall of interspersed song recall. Despite the fact that the interval between studied items was seconds in the word-CDFR task and minutes in the song-CDFR task, the results were the same— patients exhibited a recency effect which paralleled that of controls, and recall levels were reduced across all serial positions, including the most recent ones.

A caveat is that we did not have equivalents of IFR and DFR for the song data. However, if a single instance of the distractor task was sufficient to empty the short-term store, as suggested by the comparison of the IFR and DFR conditions, then it would follow that the short-term store also could not contain any songs by the time the participants were asked for song recall, at the end of the free and cued recall of the very last experimental list. Thus, we report two long-term recency effects: one for word lists and the other for a “list” of songs interpolated across the session, spanning a longer time scale.

The patients recalled 44% of the two most recently studied songs (serial positions 11-12), more than twice the number of songs they had recalled from midlist positions (11% from serial positions 6 and 7). This is despite the fact that between the very last song and the song recall they performed the digit span task, and the second-to-last song ended at least 140 seconds before the very last song. Patients have also exhibited facilitated recall of the first song they heard, more than an hour before they were asked to recall it. Finally, every patient was able to recall freely at least one song, in spite of the fact that some of them initially did not remember that they had listened to any songs at all. This observation suggests that under some conditions free recall may not reflect recollection as is traditionally assumed (McCabe, Roediger, III, & Karpicke, 2011) but either familiarity or a form implicit memory, a possibility that has been suggested by some investigators.

One straightforward way to implement this finding in aid of rehabilitation is to consider serial position effects when patients are exposed to a new environment. For example, in the Memory Link program patients are taught to use hand-held devices to record their daily experience. Our findings suggest that the patients may be more likely to remember the first and the last items so that when given tasks to perform during the day (e.g. appointments), one can prioritize the most important material by placing it at the end and the start of the list.

4.4 Conclusion

The finding that people with amnesia exhibit a long-term recency effect suggests first, that the argument against classical dual-store models can be made within the amnesic population as well as in healthy participants, favoring instead single-store models based on interference theory or hybrid dual-store models that incorporate some aspects of interference theory. Regardless of which class of models is favored, our study demonstrated that amnesic people clearly have some preserved ability to retrieve items from the long-term store, as Warrington and Weiskrantz (1968) argued when they found that while the patients were recalling the current list, there were intrusions from previous lists. Both hybrid dual-store models and single-store models can account for patients' intact recall of recency items in IFR and their impaired recall of recency items in CDFR. Finally, the finding of intact recency and long-term recency for the first item recalled on each list provides an important constraint on possible accounts of the memory deficit in amnesia: any theoretical account must explain why the deficit emerges only as the output sequence unfolds.

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Figure legends

Figure 1: Number of words recalled as a function of group and serial position. (a) Immediate free recall. (b) Delayed free recall (c) Continuous-distractor free recall. Error bars represent standard error.

Figure2: Number of words recalled as a function of group and serial position, replotted from Figure 1 with all conditions (IFR, DFR and CDFR) plotted for Controls (a) and Amnesics (b) separately. Error bars represent standard error. Note that both groups show a reduction of recency in DFR compared to IFR, and a return of recency in CDFR compared to DFR.

Figure 3: Number of words recalled at the first recall attempt as a function of group and serial position. (a) Immediate free recall. (b) Delayed free recall. (c) Continuous-distractor free recall. Error bars represent standard error.

Figure 4: Song recall as a function of group and serial position. Error bars represent standard error.

Reference List

Atkinson, R. C. & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K.W.Spence & J.T.Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory* (New York: Academic Press.

Baddeley, A. D. & Hitch, G. (1977). Recency re-examined. In S.Dornic (Ed.), *Attention and Performance VI* (pp. 647-667). Hillsdale: NJ Erlbaum.

Baddeley, A. D. & Warrington, E. K. (1970). Amnesia and the distinction between long- and short-term memory. *Journal of Verbal Learning and Verbal Behavior, 9,* 176-189.

Banich, M. T. (2011). *Cognitive Neuroscience and Neuropsychology*. Cengage Learning.

Bjork, R. A. & Whitten, W. B. (1974). Recency-sensitive retrieval processes in long-term free recall. *Cognitive Psychology, 6,* 173-189.

Brodie, D. A. (1975). Free recall measures of short-term store: Are rehearsal and order of recall data necessary?. *Memory & Cognition, 3,* 653-662.

Brodie, D. A. & Murdock, B. B. (1977). Effect of presentation time on nominal and functional serial-position curves of free recall. *Journal of Verbal Learning & Verbal Behavior, 16,* 185-200.

Brooks, D. N. & Baddeley, A. D. (2011). What can amnesic patients learn? *Neuropsychologia, 14,* 111-122.

Brown, G. D., Della, S. S., Foster, J. K., & Vousden, J. I. (2007). Amnesia, rehearsal, and temporal distinctiveness models of recall. *Psychonomic Bulletin & Review, 14,* 256-260.

Brown, G. D. A., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. *Psychological Review, 114,* 539-576.

Brown, G. G., Rosenbaum, G., Lewis, R., & Rourke, D. (1980). The effects of rehearsal rate on serial recal in korsakoff amnesia. *Neuropsychologia, 18,* 185-191.

Capitani, E., Della, S. S., Logie, R. H., & Spinnler, H. (1992). Recency, primacy, and memory: reappraising and standardising the serial position curve. *Cortex, 28,* 315-342.

Carlesimo, G. A., Marfia, G. A., Loasses, A., & Caltagirone, C. (1996). Recency effect in anterograde amnesia: evidence for distinct memory stores underlying enhanced retrieval of terminal items in immediate and delayed recall paradigms. *Neuropsychologia, 34,* 177-184.

Crowder, R. G. (1976). *Principles of learning and memory.* Hillsdale, NJ: Erlbaum.

Crowder, R. G. (1982). The demise of short-term memory. *Acta Psychologica, 50,* 291-323.

Crowder, R. G. (1993). Short-term memory: where do we stand? *Memory & Cognition, 21,* 142-145.

Davelaar, E. J., Goshen-Gottstein, Y., Ashkenazi, A., Haarmann, H. J., & Usher, M. (2005). The demise of short-term memory revisited: empirical and computational investigations of recency effects. *Psychological Review, 112,* 3-42.

Glanzer, M. & Kunitz, A. R. (1966). Two storage mechanism in free recall. *Journal of Verbal Learning and Verbal Behavior, 5,* 351-360.

Greene, R. L. (1986). Sources of recency effects in free recall. *Psychological Bulletin, 99,* 221-228.

Hogan, R. M. (1975). Inter-item encoding and directed search in free recall. *Memory & Cognition, 3,* 197-209.

Howard, M. W. & Kahana, M. J. (1999a). Contextual variability and serial position effects in free recall. *Journal of Experimental Psychology:Learning, Memory & Cognition, 25,* 923-941.

Howard, M. W. & Kahana, M. J. (1999b). Contextual variability and serial position effects in free recall. *Journal of Experimental Psychology:Learning, Memory & Cognition, 25,* 923-941.

Howard, M. W. & Kahana, M. J. (2002). When does semantic similarity help episodic retrieval? *Journal of Memory and Language, 46,* 85-98.

Hunt, R. R. & Worthen, J. B. (2006). *Memory and Distinctiveness*. Oxford: Oxford University Press.

Jonides, J., Lewis, R. L., Nee, D. E., Lustig, C. A., Berman, M. G., & Moore, K. S. (2008). The mind and brain of short-term memory. *Annual Review of Psychology, 59,* 193-224.

Kahana, M. J., Sederberg, P. B., & Howard, M. W. (2008). Putting Short-Term Memory Into Context: Reply to Usher, Davelaar, Haarmann, and Goshen-Gottstein (2008). *Psychological Review, 115,* 1119-1125.

Kolb, B. & Whishaw, I. Q. (2010). *An introduction to brain and behavior*. Worth Publishers, Incorporated.

Kucera, H. & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Laming, D. (1999). Testing the idea of distinct storage mechanisms in memory. *International Journal of Psychology, 34,* 419-426.

Mayes, A. R., Pickering, A., & Fairbairn, A. (1987). Amnesic sensitivity to proactive interference: its relationship to priming and the causes of amnesia. *Neuropsychologia, 25,* 211-220.

McCabe, D. P., Roediger, H. L., III, & Karpicke, J. D. (2011). Automatic processing influences free recall: converging evidence from the process dissociation procedure and remember-know judgments. *Memory & Cognition, 39,* 389-402.

Moscovitch, M. (1982a). A neuropsychological approach to perception and memory in normal and pathological aging. In F.I.M.Craik & S. E. Trehub (Eds.), *Aging and Cognitive Processes* (pp. 355-378). New York: Plenum Press.

Moscovitch, M. (1982b). Multiple dissociations of function in amnesia. In L.S.Cermak (Ed.), *Human Memory and Amnesia* (pp. 337-370). Hillsdale, NJ: Erlbaum Associates.

Murdock, B. B. Jr. (1962). The serial position effect in free recall. *Journal of Experimental Psychology, 64,* 482-488.

Polyn, S. M., Norman, K. A., & Kahana, M. J. (2009). A context maintenance and retrieval model of organizational processes in free recall. *Psychological Review, 116,* 129-156.

Postman, L. & Phillips, L. (1965). Short-term temporal changes in free recall. *Quarterly Journal of Experimental Psychology, 17,* 132-138.

Rosenbaum, R. S., Kohler, S., Schacter, D. L., Moscovitch, M., Westmacott, R., Black, S. E. et al. (2005). The case of KC: Contributions of a memory-impaired person to memory theory. *Neuropsychologia, 43,* 989-1021.

Ryan, L., Ostergaard, A., Norton, L., & Johnson, J. (2001). Search and Selection Processes in Implicit and Explicit Word-stem Completion Performance in Young, Middle Aged and Older Adults. *Memory and Cognition, 29,* 678-690.

Scoville, W. B. & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery and Psychiatry, 20,* 11-21.

Sederberg, P. B., Howard, M. W., & Kahana, M. J. (2008). A context-based theory of recency and contiguity in free recall. *Psychological Review, 115,* 893-912.

Strauss, E. & Spreen, O. (1991). *A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary.* New York: Oxford University Press.

Talmi, D. & Goshen-Gottstein, Y. (2006). The long-term recency effect in recognition memory. *Memory., 14,* 424-436.

Tulving, E. (1966). Subjective organization in free recall of "unrelated" words. *Psychological Review, 69,* 344-354.

Usher, M., Davelaar, E. J., Haarmann, H. J., & Goshen-Gottstein, Y. (2008). Short-term memory after all: comment on Sederberg, Howard, and Kahana (2008). *Psychological Review, 115,* 1108-1118.

Warrington, E. K. & Weiskrantz, L. (1968). New method of testing long-term retention with special reference to amnesic patients. *Nature, 217,* 972-974.

Waugh, N. C. & Norman, D. A. (1965). Primary memory. *Psychological Review, 72,* 89-104.

Wilson, M. D. (1988). The MRC psycholinguistic database: Machine readable dictionary, version 2. *Behavioral Research Methods, 20,* 6-11.

Table 1: Characteristics of patient and control participants

	Controls		Patients	
	Mean	SD	Mean	SD
Age	55.33	7.05	53	5.40
Years of Education	16	2.36	16.45	2.94
Premorbid intelligence	110.47	10.07	109.91	10.04
Digits span forward	7.27	1.33	7	0.89
Digits span backward	5.53	1.46	4.82	1.54

Note. SD=standard deviation. Premorbid intelligence was assessed using the Wechsler Test of Adult Reading.

Table2

Table 2: Neuropsychological characteristics for participants with Amnesia.

Patient	*PR*	*MS*	*JSB*	*DA*	*MT*	*RR*	*KM*	*MB*	*KC*
Age	47	52	59	55	42	56	53	55	54
Sex	M	M	M	M	M	F	F	M	M
Etiolog	Seizures	Encephalitis	Korsakoff	Encephalitis	Aneurysm	Cyst removal	Aneurysm	Aneurysm	Closed head injury
WTAR	106	120	119	117	92	96	119	119	101
WASI									
FSQ	114 82%ile	117 87%ile	121 92%ile	117 87%ile	110-119[1] High average	113 81%ile	102 55%ile	119 90%ile	96 47%ile
VSQ	116 86%ile	123 94%ile	126 96%ile	121 92%ile	100-109[1] Average	113 81%ile	82 12%ile	120 91%ile	96 47%ile
PSQ	108	99	111	106	120-129[1]	109	126	116	96

	70%ile	47%ile	77%ile	66%ile	Superior	73%ile	96%ile	86%ile	47%ile
Digit Span									
Total	10	18	25	18	16	22	16	21	17
Forward	5	8	8	7	7	7	7	7	8
Back	3	5	7	5	4	7	4	7	3
CVLT									
Immediate recall	T=33	T=43	T=29	T=15	T=7	T=33	T=15	T=31	<1%ile[1]
Short delay	0	1	0	0	0	0	2	4	<1%ile[1]
Long delay	0	1	1	0	0	0	0	2	<1%ile[1]
BVMT									
Immmediate recall	KBNA[2] 0	T=21	T=30	T=26	T=21	T=21	T=35	[4]	T=35
Delayed recall	KBNA[2] 0	T=25	T=33	T=<20	T=<20	T=<20	T=35	*Rey-O= T=24*	T=<20

Recognition	KBNA[2] <1%	11-16%ile	6-10%ile	<1%ile	11-16%ile	1-2%ile	>16%ile	[4]	1-2%ile
Fluency									
Phonemic (FAS)	[3]	43 45%ile	49 63 %ile	67 98%ile	35 30%ile	26 16%ile	26 16%	9 < 1%ile	7-13%ile[1]
Semantic (Animals)	[3]	17 19%ile	20 37%ile	23 50%ile	15 10%ile	16 12 %ile	35 99%	9 < 1%ile	50%ile[1]
WCST categories	4 >16%ile	6 >16%ile	6 >16%ile	6 >16%ile	6 >16%ile	6 >16%ile	[3]	6 >16%ile	4 >16%ile

Notes. WASI=Wechsler Abbreviated Test of Intelligence; FSQ=full scale quotient; VSQ=visual scale quotient; PSQ=performance scale quotient; WTAR = Wechsler Test of Adult Reading; CVLT=California Verbal Learning Test; BVMT=Brief Visual Memory Test; FAS=Letter fluency test; WCST= Wisconsin Card Sorting Test.

1. This description was the only "score" provided for us
2. The complex figure of the Kaplan baycrest Neuropsychological Assessment (KBNA) was administered instead of the BVMT. The values are the raw scores.
3. Not tested in this patient.
4. The Rey-Osterieth Complex Figure Test was administered instead of the BVMT.

Figure1
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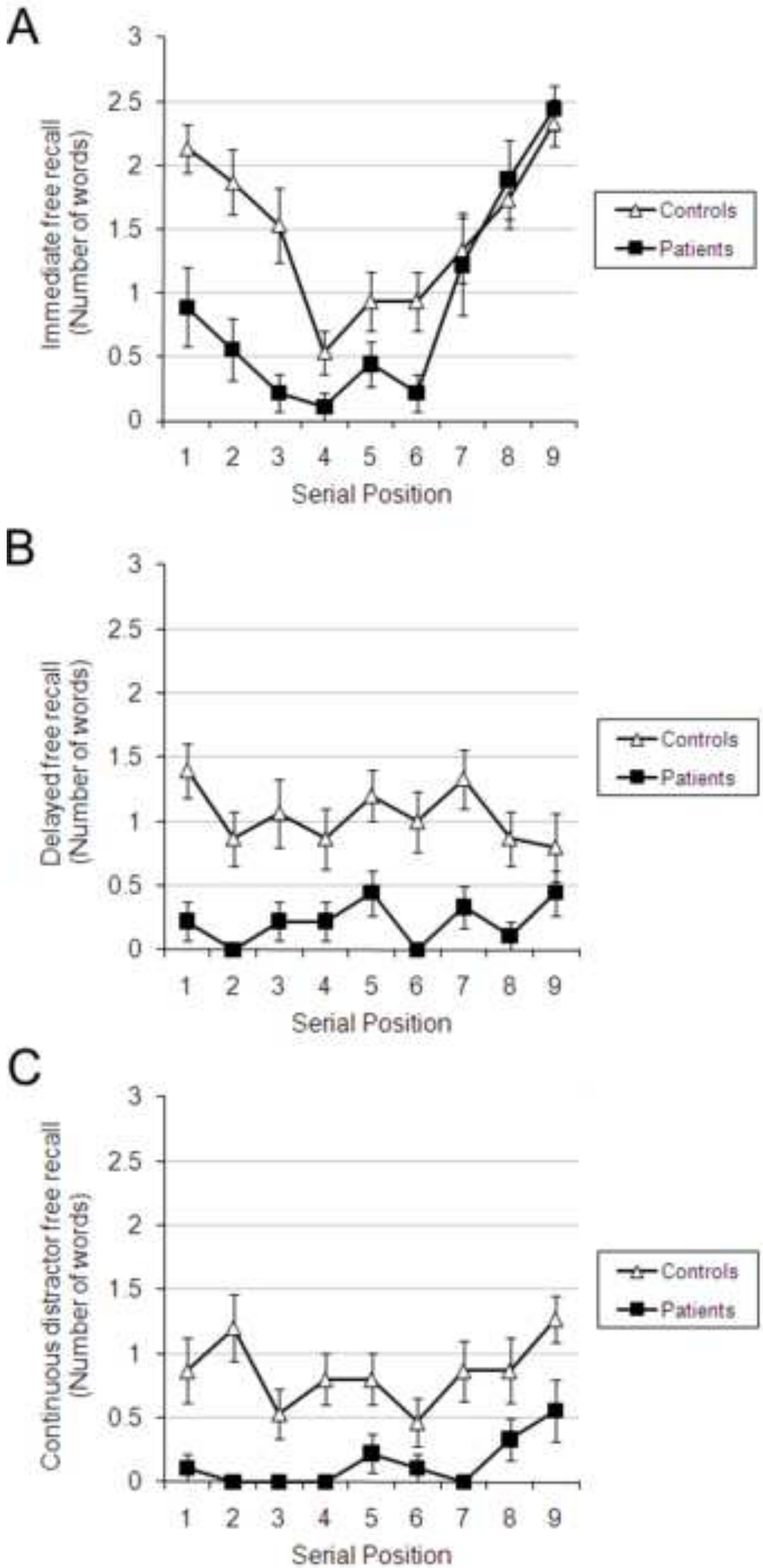

Figure2

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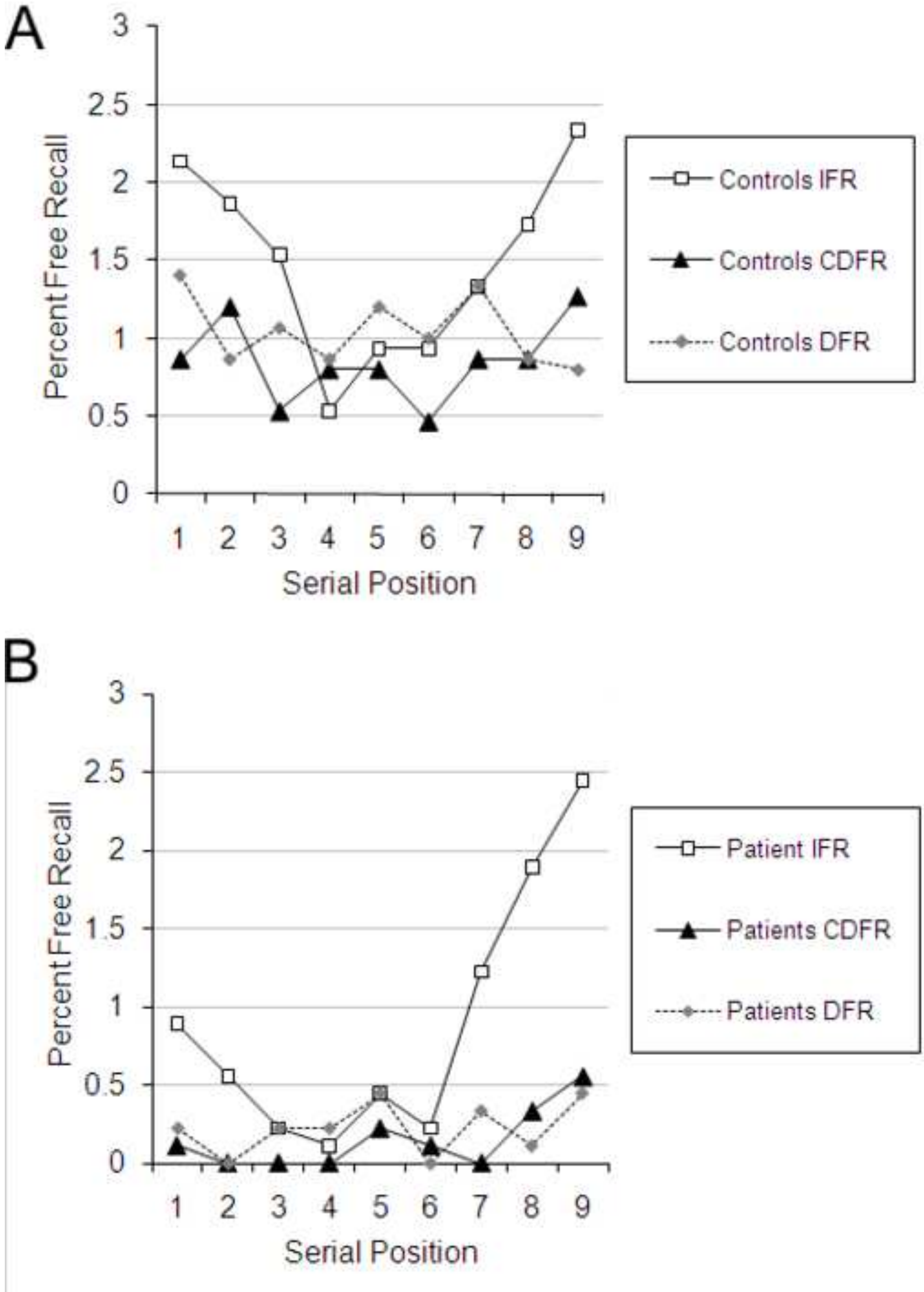

Figure3
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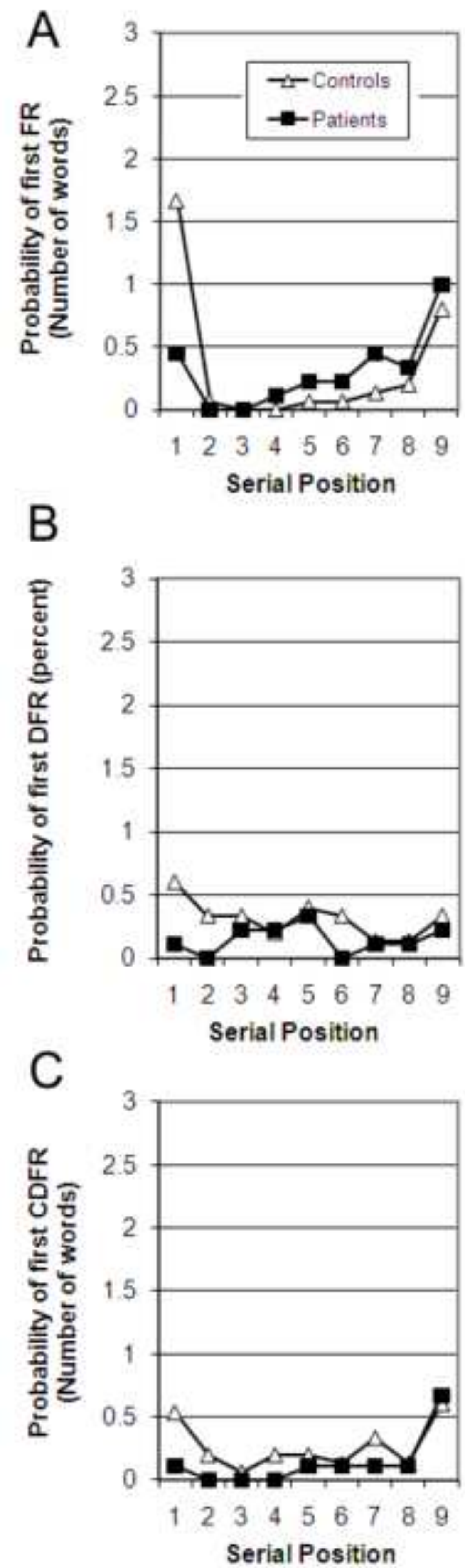

Figure4

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