BRIEF REPORTS

Amnesia, rehearsal, and temporal distinctiveness models of recall

GORDON D. A. BROWN

University of Warwick, Coventry, England

SERGIO DELLA SALA

University of Edinburgh, Edinburgh, Scotland

JONATHAN K. FOSTER

*Edith Cowan University, Perth, Australia
and University of Western Australia, Perth, Australia*

AND

JANET I. VOUSDEN

University of Warwick, Coventry, England

Classical amnesia involves selective memory impairment for temporally distant items in free recall (impaired primacy) together with relative preservation of memory for recency items. This abnormal serial position curve is traditionally taken as evidence for a distinction between different memory processes, with amnesia being associated with selectively impaired long-term memory. However recent accounts of normal serial position curves have emphasized the importance of rehearsal processes in giving rise to primacy effects and have suggested that a single temporal distinctiveness mechanism can account for both primacy and recency effects when rehearsal is considered. Here we explore the pattern of strategic rehearsal in a patient with very severe amnesia. When the patient's rehearsal pattern is taken into account, a temporal distinctiveness model can account for the serial position curve in both amnesic and control free recall. The results are taken as consistent with temporal distinctiveness models of free recall, and they motivate an emphasis on rehearsal patterns in understanding amnesic deficits in free recall.

When word lists are recalled, early-presented items are typically better recalled than are midlist items (the primacy effect), and end-list items in turn are better recalled than either primacy items or midlist items (the recency effect). Primacy effects are typically thought to reflect superior recall of items that have entered long-term memory, whereas recency items are assumed to still reside in a separate short-term memory store (Atkinson & Shiffrin, 1968). Patients with severe amnesia typically show preserved recency effects but impaired memory for earlier list items, consistent with a selective impairment of long-term memory within a dual-store model (Baddeley & Warrington, 1970; but cf. Butters & Cermak, 1974).

However, some recent theoretical models suggest that normal primacy and recency effects in free recall can be explained with a unitary temporal distinctiveness, or *ratio-rule*, approach (e.g., G. D. A. Brown, Neath, & Chater, in

press; Neath & Brown, 2006; Tan & Ward, 2000; but see Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005). Such models typically assume that recency effects reflect reducing discriminability of items as they recede into the past (Bjork & Whitten, 1974; Crowder, 1976) and that primacy arises not from consolidation in long-term memory, but from rehearsal being used to "carry forward" early-list items. Participants typically rehearse early-list items throughout list presentation, thus reducing the effective retention interval for those items (Rundus, 1971; Tan & Ward, 2000). When recall is plotted by recency of last rehearsal, primacy effects are reduced or abolished, and a unitary model can explain the resulting serial position curves (G. D. A. Brown et al., in press; Tan & Ward, 2000).

Such results suggest that it might be possible to understand the abolition of primacy associated with amnesia in terms of an abnormal rehearsal process. Rehearsals of

G. D. A. Brown, g.d.a.brown@warwick.ac.uk

items within a to-be-recalled list are frequently seen as within-list retrievals; hence, any general retrieval deficit could lead to impaired rehearsal and to a selective impairment of primacy. If so, the abnormal serial position curve in amnesia (the selective reduction of primacy) could be interpreted in terms of a general retrieval deficit in free recall, rather than of a selective deficit of long-term memory. According to such a perspective, the direction of causality would be general retrieval deficit → impaired rehearsal → selectively reduced primacy, rather than selective memory deficit → selectively reduced primacy.

How might such an account work? Provided list presentation is not too fast and rehearsal is permitted, normal participants will rehearse several different items in the gaps between presentations of to-be-remembered items. For example, if items A B C D E F . . . are presented, then (using uppercase letters for presentations and lowercase for rehearsals) a typical protocol might proceed as follows:

A a a a B b a C a b c D a b c E a b d F . . .

Thus, after presentation of the fifth item (E), the first, second, and fourth items are rehearsed. The rehearsal carries these early-list items forward through the list, presumably laying down a new trace on each occasion, with the effect of reducing the temporal delay intervening between the time at which an early-list item must be recalled and the time its most recent trace was laid down (see Tan & Ward, 2000). Assuming that each rehearsal is effectively a within-list retrieval, any retrieval deficit associated with amnesia is likely to impair the ability of a dense amnesic to use rehearsal to benefit early-list items in this way.

If an amnesic patient is unable to perform the within-list retrievals necessary to implement rehearsal, or indeed for some other reason is not able or willing to engage in cumulative rehearsal of the type normally observed, reduced primacy might therefore be observed. However (and crucially), reduced primacy would then reflect a retrieval deficit that is *general* to free recall, rather than a selective deficit in a separate memory store that gives rise to primacy effects.

The importance of rehearsal in understanding amnesic deficits is not unique to the present study (see G. G. Brown, Rosenbaum, Lewis, & Rourke, 1980; Butters & Cermak, 1974; Cermak, Naus, & Reale, 1976). We emphasize that the hypothesis under consideration is not that the *amount* of rehearsal will be diminished in amnesia, resulting in a free-recall deficit; it is well established that quantity of rehearsal per se need not predict recall (see, e.g., Craik & Watkins, 1973; Woodward, Bjork, & Jongeward, 1973). Rather, the hypothesis is that the use of rehearsal to benefit primacy items may be impaired.

Thus, our primary question is whether a temporal distinctiveness model can shed light on the amnesic pattern of preserved recency and impaired primacy (Baddeley & Warrington, 1970; Capitani, Della Sala, Logie, & Spinnler, 1992) when rehearsal in amnesia is considered. We tested this hypothesis with S.J., a severely amnesic patient.

The remainder of this article is organized as follows. We first report the free-recall performance of S.J. and of control participants using an overt rehearsal procedure (Rundus, 1971), in which participants rehearse to-be-remembered items overtly in the gaps between presented list items. Use of the overt rehearsal procedure does not change the basic effects observed in free recall (Tan & Ward, 2000), but it does allow any effects due to schedule of rehearsal to be identified. We then examined the ability of a simple mathematical formulation of a unitary model of memory (G. D. A. Brown et al., in press) to account for the data from both control and amnesic free recall through changes in a single model parameter that represents the temporal distinctiveness of memories.

METHOD

Participants

Patient. S.J., a patient suffering from dense but specific amnesia, was tested. At the time of test, S.J. suffered from a substantial circumscribed bilateral hippocampal lesion due to severe hypoxia. This was confirmed by cranial MRI 7 months after injury (Gagnon, Foster, Turcotte, & Jongenelis, 2004). MRI of S.J.'s brain revealed bilaterally increased signal within the mesial temporal lobes involving both amygdalae and hippocampi. Coronal images suggested bilateral loss of volume in the hippocampal gyri; no other atrophic changes were detected. S.J., who was age 49 at test, enjoyed a successful professional career prior to injury. Background tests (see Gagnon et al., 2004, for a complete report) revealed a superior-range IQ (a prorated WAIS-R full-scale score of 127); normal word, digit, and visuospatial short-term serial recall; and intact executive function coupled with very severe anterograde amnesia on a range of memory tests (e.g., poor prose recall, as well as a Rey figure copy score at the 100th percentile, with delayed reproduction at the 1st percentile).

Controls. S.J.'s partner was tested as a control, as were an additional control group of 17 student volunteers. The students were undergraduates and postgraduates at the University of Warwick between the ages of 18 and 30.

Stimuli

All list items were unique monosyllabic words, four or five letters in length with three or four phonemes, with frequency values (Kučera & Francis, 1967) between 10 and 50 per million and with imageability, familiarity, and concreteness values greater than 300 (Wilson, 1988).

Procedure

The free-recall performance of S.J. and of the controls was examined using the overt rehearsal procedure, in which subjects vocalize their rehearsals of preceding list items during the gaps in list presentation. All participants received 16 test lists of 16 words, preceded by two 4-item and two 8-item practice lists. Items were presented on index cards for 1 sec, with interitem gaps of 3 sec. Participants read each item aloud and were instructed to rehearse overtly any words that came to mind during the interitem gaps.

RESULTS AND DISCUSSION

S.J. and the controls both showed the normal recency effect (Figure 1, left column). As expected, the controls also showed the extensive primacy effect that is normally observed when presentation rate is slow enough to permit substantial rehearsal. S.J., in contrast, exhibited the classic amnesic pattern of substantially impaired primacy.

Figure 1 (right column) shows performance as a function of serial position of last rehearsal (Rundus, 1971; Tan & Ward, 2000). Once this factor was taken into account, primacy was virtually abolished in both S.J.'s partner and the undergraduate controls, confirming that the primacy effects resulted from shortening of primacy items' retention intervals through cumulative rehearsal. Inspection of the rehearsal protocols showed that S.J. adopted a fixed rehearsal pattern, almost invariably rehearsing only the most recently presented item in the interval before presentation of the next item. In contrast, both S.J.'s partner and the student controls rehearsed several different items in each interitem gap, and in particular rehearsed early-presented items throughout list presentation, thus effectively shortening the retention intervals for those items. These effects are illustrated in Figure 2.

Figure 2A shows for S.J., his partner, and the student controls the average movement due to cumulative rehearsal between position of presentation and position of last rehearsal. For example, the first-presented item was carried forward an average of eight positions through the list by S.J.'s partner and the other controls, leading to a position of last rehearsal midway through the list. Figure 2B shows the number of rehearsals produced by S.J. and by the controls.

Despite repeated encouragement and demonstrable understanding, S.J. consistently declined to engage in cumulative rehearsal. When asked, he stated that rehearsing earlier items was very difficult and made it impossible for him to remember any other item. Within each interitem gap, S.J. rehearsed 4.5 times on average [vs. 4.3 for the controls; $t(16) = 0.005$, $p = .99$]. However, S.J. consistently rehearsed items noncumulatively during the interitem gaps, so that he did not rehearse *different* items [controls rehearsed 3.1 different items on average, whereas S.J. rehearsed only 1.03 different items; $t(16) = 13.7$, $p < .001$]. Thus, the results are consistent with the suggestion that S.J.'s memory deficit led to his inability to retrieve and rehearse items (other than the most recent one) during list presentation.

S.J.'s intrusion errors were examined, since a high level of such errors is associated with frontal/dysexecutive problems (Baldo, Delis, Kramer, & Shimamura, 2002). Consistent with his intact executive function, S.J. made very few such errors; he made a total of nine intrusion errors, only two of which were from previous lists. Thus, when strategic rehearsal is taken into account, S.J.'s free-recall serial position curve differs from the normal pattern only quantitatively.

Figure 1. Free-recall serial position curves. Left column: Free recall plotted by serial position. Right column: Recall by serial position of last rehearsal, together with a model fit (solid line; see the text for details of the model). Points for early serial positions are necessarily based on small numbers of data points.

Figure 2. Rehearsal effects for S.J., S.J.'s partner, and the student controls. (A) Average movement due to cumulative rehearsal between position of presentation and position of last rehearsal. (B) Number of rehearsals.

In terms of psychological interpretation, this suggests that the dissociation in S.J.'s serial position curve, which showed the classic amnesic pattern of reduced performance on early-list items, can be understood in terms of an impaired or nonstrategic rehearsal process. Given S.J.'s intact frontal function, the impaired rehearsal seems likely to reflect a basic episodic memory retrieval deficit that is manifested in the within-list retrieval needed for rehearsal, as well as in recall of items at the end of list presentation.

However a more convincing account could be given if it could be shown that the difference between amnesics' and controls' serial position curves, plotted in terms of last rehearsal, could be accounted for with a simple model that contains no separate stores. It is to this issue that we now turn.

Model

We examined whether a unitary temporal distinctiveness model could fit the data from both S.J. and controls, using a model that has been applied to a wide range of serial- and free-recall data (G. D. A. Brown et al., in press; Lewandowsky & Brown, 2005; Lewandowsky, Duncan, & Brown, 2004; Neath & Brown, 2006). For free recall, this model predicts primacy and recency effects without assuming separate short-term and long-term stores. Full details of the model's implementation and behavior can

be found in G. D. A. Brown et al. (in press); a simplified version is presented here.

The model assumes that the confusability of memory traces for items i and j is

$$\eta_{i,j} = \left(\frac{TD_i}{TD_j} \right)^c,$$

where TD_i and TD_j are the items' temporal distances at the time of recall ($i < j$), and larger c reflects increased memory discriminability. For example, items that occurred 2 and 3 sec before recall will be less confusable $(2/3)^c$ than will items that occurred 4 and 5 sec before recall $(4/5)^c$. The probability of discriminating the trace of a memory item, given its temporal location as a cue, is assumed to be inversely proportional to that trace's summed similarity to the traces of the n other list items,

$$P(D_i) = \frac{1}{\sum_{k=1}^n (\eta_{i,k})},$$

and item retrieval probability is a thresholding function of D_i ,

$$P(R_i) = \frac{1}{1 + e^{-s(D_i - t)}},$$

with parameters s (slope) and t (threshold). The total recall probability for each item is summed over retrieval cues.

The model was fit to the data showing recall performance as a function of serial position of last rehearsal. Best-fit curves for the model described above are shown in Figure 1 (right column), where it is apparent that the model captures the recency shown by all three groups. The parameter values were meaningful: Best-fit estimates of c were 3.9, 4.8, and 5.1 for S.J., his partner, and the control undergraduates, respectively, and the respective estimated values of t (and s) for the three groups were .48 (13.2), .63 (10.0), and .67 (6.69). In psychological terms, the general memory discriminability parameter (c) was lowest for the amnesic patient and highest for the undergraduates, as was the threshold parameter. The parameter s , which can be thought of as capturing the amount of noise on a noisy threshold, was highest for the amnesic patient and lowest for the control group of undergraduates.

The key point is that the qualitative differences in the three serial position curves can be interpreted in terms of merely quantitative changes in memory retrieval parameters when the abnormal pattern of rehearsal during free recall is taken into account.

CONCLUSION

This study was motivated by the suggestion that the primacy effect normally observed in free recall reflects the use of rehearsal to carry forward early-list items selectively, rather than the contribution of a separate store (Tan & Ward, 2000). It was hypothesized that the selective abolition of primacy in classical hippocampal amnesia could therefore be understood in terms of abnormal rehearsal patterns resulting from a general retrieval deficit.

Consistent with the hypothesis, it was shown that the qualitative distinction between the free-recall performance of a classic hippocampal amnesic patient and controls disappears when the pattern of strategic rehearsal is considered. The remaining quantitative differences can be captured in a simple unitary model without an assumption of separate short-term and long-term memory stores, thus (1) undermining the inference from amnesic free-recall performance to separate memory stores and (2) motivating an emphasis on rehearsal patterns in understanding amnesic deficits in free recall.

We note the possibility that S.J.'s free recall might have revealed primacy effects if strategic rehearsal rather than recall performance had been emphasized. Although it is difficult to exclude this proposal on the basis of the present data, as noted above we made clear to S.J. that cumulative rehearsal would be appropriate, and yet he declined to rehearse in such a way. S.J.'s failure to rehearse normally is paradoxical, because at the end of the list he was typically able to recall the most recent three or four items. Why could S.J. not therefore retrieve the last few items for rehearsal after each new item was presented? The failure to retrieve multiple items during list presentation, even though such retrieval is possible at list end, could arise if S.J.'s retrieval of each item were slower or more effortful than normal. Within-list cumulative rehearsal requires not just the retrieval of multiple items, but that such retrieval be both fast enough to occur before the presentation of the next list item and effortless enough not to interfere with consolidation of the previous item. Equivalently, S.J. may benefit more than controls by his repeated (noncumulative) rehearsal of the most recent item; such repetition would of course not be possible if earlier items were being retrieved and rehearsed instead. Such potential explanations are speculative, but that fact does not alter the key conclusion that the lack of primacy shown by S.J. can be accounted for in terms of S.J.'s failure to rehearse cumulatively.

Finally, it should be noted that the full pattern of memory deficits associated with amnesia is a complex one, and no claim to a comprehensive account is made here. In particular, a complete model will need to go beyond the present demonstration that a temporal distinctiveness model can account for the absence of primacy in both normal and amnesic participants when recency of rehearsal is taken into account. Specifically, a full model of the rehearsal process will be needed; such an account lies outside the scope of the present project, and will in any case need to be supported by a wider range of data than those presented here.

AUTHOR NOTE

This research was supported by ESRC Grants R000239002 and RES 000231038 and by BBSRC Grant 88/S15050. Correspondence concerning this article should be addressed to G. D. A. Brown, Department of Psychology, University of Warwick, Coventry CV34 6PD, England (e-mail: g.d.a.brown@warwick.ac.uk).

REFERENCES

- 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* (Vol. 2, pp. 89-195). New York: Academic Press.
- BADDELEY, A. D., & WARRINGTON, E. K. (1970). Amnesia and the distinction between long- and short-term memory. *Journal of Verbal Learning & Verbal Behavior*, **9**, 176-189.
- BALDO, J. V., DELIS, D., KRAMER, J., & SHIMAMURA, A. P. (2002). Memory performance on the California Verbal Learning Test-II: Findings from patients with focal frontal lesions. *Journal of the International Neuropsychological Society*, **8**, 539-546.
- BJORK, R. A., & WHITTEN, W. B. (1974). Recency-sensitive retrieval processes in long-term free recall. *Cognitive Psychology*, **6**, 173-189.
- BROWN, G. D. A., NEATH, I., & CHATER, N. (in press). A temporal ratio model of memory. *Psychological Review*.
- BROWN, G. G., ROSENBAUM, G., LEWIS, R., & ROURKE, D. (1980). The effects of rehearsal rate on serial recall in Korsakoff amnesia. *Neuropsychologia*, **18**, 185-191.
- BUTTERS, N., & CERMAK, L. S. (1974). Some comments on Warrington and Baddeley's report of normal short-term memory in amnesic patients. *Neuropsychologia*, **12**, 283-285.
- CAPITANI, E., DELLA SALA, S., LOGIE, R. H., & SPINNLER, H. (1992). Recency, primacy, and memory: Reappraising and standardising the serial position curve. *Cortex*, **28**, 315-342.
- CERMAK, L. S., NAUS, M. J., & REALE, L. (1976). Rehearsal strategies of alcoholic Korsakoff patients. *Brain & Language*, **3**, 375-385.
- CRAIK, F. I. M., & WATKINS, M. J. (1973). The role of rehearsal in short-term memory. *Journal of Verbal Learning & Verbal Behavior*, **12**, 599-607.
- CROWDER, R. G. (1976). *Principles of learning and memory*. Hillsdale, NJ: Erlbaum.
- 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.
- GAGNON, S., FOSTER, J. K., TURCOTTE, J., & JONGENELIS, S. (2004). Involvement of the hippocampus in implicit learning of supra-span sequences: The case of S.J. *Cognitive Neuropsychology*, **21**, 867-882.
- KUČERA, H., & FRANCIS, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.
- LEWANDOWSKY, S., & BROWN, G. D. A. (2005). Serial recall and presentation schedule: A micro-analysis of local distinctiveness. *Memory*, **13**, 283-292.
- LEWANDOWSKY, S., DUNCAN, M., & BROWN, G. D. A. (2004). Time does not cause forgetting in short-term serial recall. *Psychonomic Bulletin & Review*, **11**, 771-790.
- NEATH, I., & BROWN, G. D. A. (2006). SIMPLE: Further applications of a local distinctiveness model of memory. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 46, pp. 201-243). San Diego: Academic Press.
- RUNDUS, D. (1971). Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology*, **89**, 63-77.
- TAN, L., & WARD, G. (2000). A recency-based account of the primacy effect in free recall. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **26**, 1589-1625.
- WILSON, M. (1988). MRC Psycholinguistic Database: Machine-usable dictionary, version 2.00. *Behavior Research Methods, Instruments, & Computers*, **20**, 6-10.
- WOODWARD, A. E., BJORK, R. A., & JONGEWARD, R. H. (1973). Recall and recognition as a function of primary rehearsal. *Journal of Verbal Learning & Verbal Behavior*, **12**, 608-617.

(Manuscript received March 19, 2006;
revision accepted for publication June 26, 2006.)