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Charting the acquisition of semantic knowledge in a case of developmental amnesia

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Abstract

We report the acquisition and recall of novel facts by Jon, a young adult with early onset developmental amnesia whose episodic memory is gravely impaired due to selective bilateral hippocampal damage. Jon succeeded in learning some novel facts but compared with a control group his intertrial retention was impaired during acquisition and, except for the most frequently repeated facts, he was also less accurate in correctly sourcing these facts to the experiment. The results further support the hypothesis that despite a severely compromised episodic memory and hippocampal system, there is nevertheless the capacity to accrue semantic knowledge available to recall.

Keywords

Developmental amnesia; Episodic memory; Semantic memory; Hippocampus; Learning

There is a great deal of controversy about the role of the hippocampus and its surrounding cortices in relation both to the distinction between episodic and semantic memory and, within episodic memory tests, to recognition compared with recall. There is evidence that, unlike recall, both semantic memory and recognition are relatively preserved in patients with selective hippocampal damage (e.g., Aggleton, Vann, Denby, Dix, Mayes, Roberts & Yonelinas; Baddeley, Vargha-Khadem, & Mishkin, 2001). But there is also evidence that both semantic memory and recognition are impaired in such patients (e.g., Manns, Hopkins, Reed, Kitchener, & Squire, 2003; Manns, Hopkins, & Squire, 2003; Wixted & Squire, 2004). The evidence is also mixed when considering other patients with more extensive brain damage that includes damage to the hippocampus. For example, Verfaellie, Koseff, and Alexander (2000) described two adult patients, one of whom had extensive medial temporal lobe damage and largely failed to acquire new semantic knowledge, whereas the other, who had more selective damage to the hippocampus, did acquire new semantic knowledge, though not without impairment. And, in another patient with hippocampal damage sustained in adulthood, Holdstock, Mayes, Isaac, Gong, and Roberts (2002) found that neither rapid acquisition of semantic knowledge, which

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they suggest is hippocampal-dependent, nor the slow acquisition of semantic knowledge, which they suggest is not hippocampal-dependent, was completely normal.

The present study investigated the acquisition of semantic knowledge in another patient, Jon (Vargha-Khadem et al., 1997). The presumed cause of Jon's neuropathology is hypoxia-ischemia. He was born prematurely at 26 weeks and suffered from severe apnea, requiring incubation as well as positive pressure ventilation. In early adulthood, MRI scans revealed that there was a 50% bilateral reduction in his hippocampus but no apparent damage to the surrounding parahippocampal cortices or to other parts of the brain.

Jon's performance is impaired on formal tests of episodic memory, particularly in recall tests, but unimpaired in formal tests of previously acquired semantic memory knowledge (Vargha-Khadem et al., 1997). In recognition memory, his performance has been mostly unimpaired but not always (see Baddeley et al., 2001; Gardiner, Brandt, Vargha-Khadem, Baddeley, & Mishkin, 2006). Also, Jon's brain activity in recognition tests, measured by eventrelated potentials (ERPs), did not show the normal late positive component (LPC) associated with recollection but did show an earlier negative component (sometimes referred to as the N400 effect) associated with familiarity (Düzel, Vargha-Khadem, Heinze, & Mishkin, 2001). And Jacoby's (1991) process dissociation procedure in recognition tests revealed that Jon's recollection process was impaired, but not his familiarity process (Brandt, Gardiner, Vargha-Khadem, Baddeley, & Mishkin, 2008).

The main aim of the present study was to chart Jon's acquisition of semantic knowledge under controlled experimental conditions and thereby to provide further information about the circumstances under which he can acquire such knowledge. We presented Jon and a matched control group with a set of novel facts to be learned to criterion in a first learning session. In a second session, some weeks later, half of those facts were re-presented for further learning trials, along with a similar number of new facts. A third session, again some weeks later, involved a single final recall test for all the novel facts, mixed together with an equal number of comparable facts well known in the general population and hence part of knowledge normally represented in semantic memory. This was followed by a source recall test in which participants were asked whether the recalled fact was one that they had learned during the course of the experiment or one that they had learned prior to it and somewhere else.

Intertrial retention and forgetting during the acquisition trials were analysed using a procedure introduced by Tulving (1964). In this analysis, responses on each successive pair of learning trials (Trials 1 and 2, Trials 2 and 3, etc.) are classified into one of four categories: CC: recalled on both trials; CN: recalled on the first but not the second trial; NC: recalled on the second but not the first trial; and NN: recalled on neither trial. Of particular interest are the CC and CN categories which, respectively, measure intertrial retention and intertrial forgetting. As good recall from episodic memory considerably facilitates the acquisition of semantic knowledge (see Conway, Gardiner, Perfect, Anderson, & Cohen, 1997), we predicted that Jon would show relatively lower levels of CC and relatively higher levels of CN, compared with the control group.

We also predicted that, compared with a control group, Jon's memory for the novel facts in the final recall test would be impaired but he would show no such impairment in his memory for facts well known to the general population. Finally, we predicted that, compared with a control group, Jon would be less likely to correctly source the novel facts he recalls to the experiment and more likely to attribute them to knowledge he had acquired prior to the experiment.

1. Methods

1.1. Participants

Jon was 25 years old when the experiment was run. His full verbal IQ score was 114, with verbal and performance scores of 108 and 120, respectively. Eight other males, mostly first-year undergraduates, were recruited (and tested) at the University of Sussex for a control group and matched individually with Jon for age (mean age 23 years) and IQ scores (mean scores of 112, full scale; 110, verbal scale; and 115, performance scale). Jon was tested at the Developmental Cognitive Neuroscience Unit, University College of London Institute of Child Health. Both institutions gave ethical approval and participants gave informed consent.

1.2. Materials

One hundred facts were chosen from various encyclopaedias on the basis that half of the facts might be known, and half unknown, by participants. In pre-testing, all 100 facts were presented in question form to a small group of participants who did not take part in the experiment. From their responses, the facts were divided between 46 that most participants knew (at most, only one person did not know the fact) and 46 that most participants did not know (at most, only one person did know the fact). In the experiment, each participant was tested on the 46 presumably unknown facts, so that if a participant knew any of these facts they could be excluded. In this way, an individual set of 36 facts, unknown to each participant, was selected. A further set of 36 facts (identical for all participants) from among those 46 that were known in the initial pretesting was selected for a final recall test.

The facts were mostly statements of historical, geographical, political, biological or other cultural kinds of knowledge to do with sport or the arts and were all expressible in the form of questions and answers. Examples of obscure facts included: ‘Of which country is Nairobi the capital? What is the national currency called in Switzerland? What is the name of the small Japanese stove used for outdoor cooking?’ Examples of well-known facts included: ‘Who is the president of the United States of America? What is the capital of France? What was the name of Tarzan’s girlfriend?’

1.3. Design and procedure

For each participant, 36 novel facts selected for the acquisition trials, which were presented orally in question and answer form, were arbitrarily divided into three sets of 12. One set of 12 was presented only in the first of two learning sessions. Another set of 12 was presented only in the second session. And a third set of 12 was presented in both sessions. In each learning session, criterion was set at 20/24 correct on two successive trials or, if that criterion was not achieved, a maximum of 6 acquisition trials. Participants were informed, prior to the acquisition trials, what the learning criteria were.

In a final recall test, participants were presented with all 36 factual questions from the acquisition trials, together with the 36 factual questions the answers to which were generally well known in the population tested. Participants were informed that some of the questions had been previously encountered during the experiment and that some had not. Following each answer, participants were then required to make one of two source judgements in answer to the question of where they had learned the fact: ‘during the experiment’ or ‘somewhere else, such as school, or at home, or from friends’.

The three test sessions were separated by intervals of 6–8 weeks. During acquisition trials, the 24 questions were read aloud by the experimenter and participants responded orally, if they could. If not, the experimenter read aloud the answer. Participants were informed that they would be asked questions that they were to try to answer without guessing and that, if they did

not know the answer, they would be told what it was before the next question. A similar procedure applied in the final recall tests.

2. Results

In the first session, the control group reached the criterion of two successive trials with 20/24 correct at an average of 3.5 trials. Jon did not achieve this criterion. By the sixth and last trial, Jon had learned only 13/24 facts. In the second session, 12 of the facts that had been learned in the first session were selected arbitrarily, on an individual basis for each participant, for inclusion along with the other 12 facts that had not been presented before. In this session, on average the control group reached the criterion of two successive trials with 20/24 correct at 4.13 trials, slightly more trials than required in the first session. Jon again did not achieve this criterion. By the sixth and last trial Jon had learned 16/24 facts.

All four measures of intertrial performance are shown in Table 1, averaged over the varying numbers of acquisition trials for each participant. The most informative measures are the conditional ones in the last two rows of the table, particularly CN, which indicates the likelihood of not recalling a fact on Trial $n + 1$ given that it was recalled on Trial n, and hence reflects intertrial forgetting, and CC, which conversely reflects intertrial retention. One-sample *t*-tests showed that Jon's CN scores were significantly higher than those of the controls both in the first, $t\ (7) = 26.100$, $p < .0001$, and in the second learning session, $t\ (7) = 17.582$, $p < .001$. Jon's CC score was also significantly lower than that of the controls in the first learning session, $t\ (7) = 6.130$, $p < .001$.

Table 2 summarizes correct fact recall from the final recall test. There was very little incorrect fact recall (out of the total of 36 questions for the novel facts, there were only 3 instances in Jon's case and an average total of 2.6 instances in the control group). Recall of facts learned only in the first session was relatively poor, both by the control group and by Jon. Recall scores for facts learned only in the second learning session, or in both first and second sessions, were higher, but Jon's scores remained lower than those of the control group. A one-sample *t*-test showed that Jon's recall (averaged over all three learning conditions because of poor recall, particularly for the first session) was significantly lower than that of the controls, $t\ (7) = 3.714$, $p < .01$. In marked contrast, Jon's recall score for facts known prior to the experiment was little different to that of the control group.

Table 3 summarizes the results from the source recall test. These data were conditionalized on correct fact recall. Because this test was a two-alternative forced-choice test, scores above .50 reflect correct source recall. Jon's ability to correctly attribute the novel facts he recalled was impaired, compared with the control group, only for the first and second sessions, with one-sample *t*-tests, $t\ (7) = 3.054$, $p < .02$ and $t\ (7) = 2.886$, $p < .03$, respectively. For bothsession facts, Jon's perfect score exceeded that of the controls, $t\ (7) = 2.436$, $p < .05$. Jon and the control group were also highly and similarly accurate in their source recall for facts known prior to the experiment.

3. Discussion

The measures of intertrial forgetting and retention during the acquisition trials provide further evidence of the difficulty of acquiring semantic knowledge without the full support of episodic memory. That the control group showed less intertrial forgetting and more intertrial retention is presumably a direct reflection of their greater ability to use episodic memory to support learning, though Jon's greater intertrial forgetting might to some extent also reflect greater loss of recently acquired semantic knowledge. In these acquisition trials, Jon's performance never approached the learning criteria and hence, compared with the control group, he experienced

far more repetitions of the facts that he did learn, as well as of those that he did not learn. It seems, then, that substantial repetition may be an important factor in Jon's ability to acquire knowledge in semantic memory in his everyday life, as is also suggested by observation and anecdotal reports. For this reason, perhaps, his ability to recall those facts that he had learned prior to the experiment was no worse than that of the control group. Semantic memory acquisition is not completely normal in Jon and he may well have required more repetitions to gain this equivalent ability.

Jon's accuracy in correctly sourcing facts that had been learned prior to the experiment was very high, and little different from that observed in the control group. And for facts learned in both sessions though not those learned in either one alone, where his performance was impaired, Jon outperformed the control group. The facts that Jon learned in both sessions were, of course, those that had been most frequently repeated. These high levels of source recall, however, do not necessarily imply that prior learning episodes were remembered in the episodic memory sense of mentally re-living the learning experience. They may only imply different abstract knowledge of those episodes. Moreover, when Jon was asked whether he just knew the facts or could actually 'remember' the learning episodes (as defined by Tulving's 1985 remember-know paradigm), Jon claimed to remember all of the facts, including those known prior to the experiment. The control group mostly claimed to remember learning the novel facts and just to know those facts learned prior to the experiment. These observations provide further evidence that Jon's reports of remembering indicate high confidence rather than qualitatively distinct recollective experiences (Baddeley et al., 2001; Gardiner et al., 2006). Differences in the apparent strength of the knowledge underlying the two types of fact — well learned prior to the experiment versus newly learned during the experiment — may also have provided some information for the source recall judgements. Source recall may usually reflect episodic memory but it need not necessarily do so.

Taken altogether, our findings further support the hypothesis that despite a severely compromised episodic memory and hippocampal system, there is nevertheless the capacity to accrue semantic knowledge available to recall. The acquisition of such knowledge may be mediated by cortical regions subjacent to the hippocampi, if those regions are spared, as they seem to be in Jon's case.

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Table 1

Mean proportions of responses across successive pairs of learning trials in each learning session (rows 1 and 2) and conditional mean proportions given recall (rows 3 and 4), with standard deviations in parentheses

	Session 1				Session 2			
	CC	**CN**	**NC**	**NN**	**CC**	**CN**	**NC**	**NN**
Controls	.67 (.08)	.01 (.01)	.20 (.07)	.12 (.07)	.63 (.05)	.00 (.00)	.23 (.05)	.14 (.04)
Jon	.29	.06	.14	.51	.38	.01	.12	.48
Controls	.75 (.07)	.01 (.01)	.23 (.06)	—	.70 (.05)	.00 (.00)	.25 (.08)	—
Jon	.59	.12	.29	—	.73	.05	.24	—

Table 2

Mean overall proportions of correct responses in the final recall test as a function of fact learning history, with standard deviations in parentheses

Overall Recall	Fact learning history			
	First session	Second session	Both sessions	Known previously
Controls	.20 (.12)	.41 (.13)	.79 (.14)	.80 (.04)
Jon	.17	.33	.50	.83

Table 3

Mean conditional proportions for correct source recall in the final recall test as a function of fact learning history, with standard deviations in parentheses

	Fact learning history			
	First session	**Second session**	**Both sessions**	**Known previously**
Controls	.40 (.37)	.81 (.31)	.87 (.15)	.98 (.24)
Jon	.00	.50	1.00	.97