Research Report

IMPLICIT AND EXPLICIT MEMORY FOLLOWING SURGICAL ANESTHESIA

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Abstract—*Paired associates were presented to 25 surgical patients following the induction of anesthesia by thiopental, vecuronium, and isoflurane. Postoperative testing (immediately or after two weeks) showed no free recall for the list; nor was there significant cued recall or recognition, compared to a matched control list. However, a free-association task showed a significant priming effect on both immediate and delayed trials. At least under some conditions, adequate surgical anesthesia appears to abolish explicit, but not implicit, memory for intraoperative events.*

General surgical anesthesia, when applied in adequate doses, results in an apparent loss of consciousness, as indicated by: (a) the lack of spontaneous movement and motor response to instructions; (b) suppression of autonomic and skeletal responses to intraoperative stimuli such as incisions; (c) absence of retrospective awareness of pain; and (d) postoperative amnesia for surgical events such as conversations among the medical team. Thus, by definition, adequately anesthetized patients rarely show any recall or recognition of surgical events. Nevertheless, there is some evidence that surgical events may be processed even by adequately anesthetized patients, resulting in the encoding of memory traces that can affect subsequent task performance (for reviews, see Bennett, 1987, 1988; Jones, 1989; Kihlstrom & Schacter, 1990; Millar, 1987; Rosen & Lunn, 1987; Trustman, Dubovsky, & Titley, 1977). For example, at least some components of the auditory evoked potential are preserved during anesthesia. In addition, patients occasionally show adverse postoperative responses—perhaps an inexplicable dislike for their surgeons, or a bad dream—that, upon investigation, seem related to some untoward event that occurred during the operation (Levinson, 1965). Finally, it has been reported that patients can comply postoperatively with instructions given during surgery for simple motor behaviors (Bennett, Davis, & Giannini, 1985; Goldmann, Shah, & Hebden, 1987), and even respond positively to therapeutic suggestions (Evans & Richardson, 1988; Furlong, 1990; Pearson, 1961). Reports such as these have kept alive the question of whether intraoperative events may be encoded in memory and influence postoperative experience, thought, and action, despite adequate surgical anesthesia.

A new perspective on this question is offered by recent evidence from a wide variety of paradigms indicating that events can influence subsequent behavior even though they themselves are not consciously remembered. For example, patients suffering the amnesic syndrome following bilateral damage to the medial temporal lobe and diencephalon are unable to recollect words that they have recently seen, but nevertheless show significant priming effects when asked to complete word stems or word fragments (Graf, Squire & Mandler, 1984; Schacter, 1985; Warrington & Weiskrantz, 1974). Similarly, hypnotizable subjects who have received suggestions for posthypnotic amnesia will fail to remember words that they learned while hypnotized, but nonetheless show priming effects when generating word associations or category instances (Kihlstrom, 1980). This sort of evidence supports a distinction between explicit memory, which requires the conscious recollection of a previous episode, and implicit memory, as revealed by a change in task performance that is attributable to such an episode (Graf & Schacter, 1985; Schacter, 1987; see also Jacoby & Dallas, 1981; Kihlstrom, 1987).

An increasingly large experimental and clinical literature indicates that explicit and implicit memory are dissociable (Richardson-Klavehn & Bjork, 1988; Schacter, 1987). Accordingly, the question about postoperative memory may be reformulated as follows: given that adequate general anesthesia abolishes explicit memory for surgical events, what effects does it have on implicit memory? Reports of postoperative response to simple instructions and therapeutic suggestions, in the absence of conscious memory for these communications, provide suggestive evidence for the preservation of implicit memory. However, studies employing more conventional procedures derived from the laboratory study of memory have been equivocal (for reviews, see Kihlstrom & Schacter, 1990; Trustman, Dubovsky, & Titley, 1977). Some positive findings have been reported (Millar & Watkinson, 1983; Stolzy, Couture, & Edmonds, 1989), but other studies have yielded negative results (Eich, Reeves, & Katz, 1985). Unfortunately, the few studies that have been performed on this topic have employed a variety of anesthetic procedures and experimental paradigms. The present experiment was intended as a preliminary test of the hypothesis that explicit and implicit memory are dissociable after surgical anesthesia, using a fixed anesthetic technique and a well-established implicit memory paradigm.

METHOD

Subjects

A total of 30 surgical patients (15 men and 15 women, median age = 39), were recruited for the experiment. The patients were scheduled for gynecological, orthopedic, abdominal, or vascular procedures, and most were in good health (92% were in Class 1 or 2 according to the physical status classification of the American Society of Anesthesiologists). At the time of giving informed consent,

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they were told that a tape-recorded message would be played to them while they were anesthetized, and that they would receive two tests of memory for its contents—an immediate test in the recovery room and a telephone followup two weeks later.

Materials

This experiment employed two lists of paired associates developed by Kihlstrom (1980, Experiment 1). Each consisted of 15 stimulus terms (cues) and the most frequent response (targets) to each (Palermo & Jenkins, 1964). The cue-target pairs in the two lists were closely matched in terms of their stimulus-response probabilities (M = 0.51). One reading of each list consumed approximately 45 sec. A series of different randomizations of each list was recorded for presentation on auto-reverse cassette players.

Procedure

Anesthesia was induced with intravenous thiopental (4–5 mg/kg), accompanied by vecuronium (0.1 mg/kg) to produce paralysis of the skeletal musculature, and maintained with a 1% end-tidal concentration of isoflurane (actual average concentration at first incision, 1.42%; at last stitch, 1.00%); no nitrous oxide was given. After one tape was randomly selected, the tape recorder was started at the time of first skin incision and played continuously until the last skin stitch; thus each patient received several aural presentations of one list (critical items), with the other list serving as a control (neutral items). The patients received intravenous morphine sulphate (0.05 mg/kg) when muscle relaxation was reversed. After tracheal extubation, the patients were taken to the recovery room. There they received additional intravenous morphine sulfate until they were comfortable and ready for the postoperative interview. No benzodiazepines (e.g., diazepam) were administered pre, intra, or postoperatively.

The experimenter who conducted the postoperative testing was blind to the tape played for the patient during surgery. For free recall, subjects were reminded that they had been read some words during surgery, and asked to recall any that they remembered. For cued recall, they were read the cues of both critical and neutral lists, in one of three random orders, and asked if any items reminded them of a word they had been presented during surgery. For free association, they were read the same cues again, in a new random order, and asked to report the first word that came to mind. For the recognition test, they were read the cue-target pairs in yet a third random order, and asked if any items had been read during surgery. Cued recall always followed free recall, and recognition was always last. Free association preceded free and cued recall for half the subjects, and followed these tests for the remainder.

RESULTS

Although 30 patients participated in the initial phase of the experiment, followup testing could not be completed for four individuals, and one patient was discarded for technical reasons. This report concerns only those 25 patients who received both immediate and delayed tests of memory. For these patients, median time under anesthesia was 81.5 min. The tape was played for a median of 50 min, or approximately 67 repetitions of the list. The median delay in the recovery room before the immediate test trial was 87 min, and a median of 14 days elapsed before the retest.

The mean proportions of critical and neutral target items produced on the cued recall, recognition, and free association tests are shown in Table 1. A 2 × 3 × 2 within-subjects analysis of variance (measure: cued recall, recognition, or free association; targets: critical or neutral; trial: immediate or delayed) applied to the items produced on the various memory tests yielded a significant interaction between measures and targets, $F(2, 48) = 5.54$, $MS_e = .006$, $p < .001$. In order to determine the source of this effect, the overall analysis was decomposed into separate ANOVAs on each measure of memory.

Explicit Memory

None of the patients showed any memory for intraoperative events upon free-recall testing, either immediately after surgery or after the two-week delay. Similar results were obtained with cued recall and recognition testing. A 2 × 2 repeated-measures analysis of variance (ANOVA) of cued-recall scores showed no significant effects of either targets (critical or neutral) or trial (immediate or delay) and no interaction, all $F < 1$. A similar ANOVA of recognition scores also yielded no significant effects, all $F < 2$. Thus, although subjects produced a small number of target items on the cued recall and recognition tests these targets were drawn equally from the critical and neutral lists. (The high standard deviations, relative to means, for cued recall and recognition reflect the spontaneous use of a guessing strategy by some subjects.)

Table 1. *Response to tests of explicit and implicit memory*

	Percentage of Targets Elicited			
	Immediate		Delayed	
Test	Critical	Neutral	Critical	Neutral
Cued Recall	12.8 (27.1)	12.0 (23.6)	11.7 (25.5)	10.9 (21.9)
Recognition	29.3 (40.4)	27.5 (37.3)	20.0 (31.9)	20.8 (32.8)
Free Association	60.0 (13.5)	54.4 (11.8)	66.1 (13.6)	57.9 (18.0)

Note. Standard deviations in parentheses. n = 25.

Implicit Memory

Rather different results were obtained with the free-association test of implicit memory. The ANOVA showed a significant effect of targets, $F(1, 24) = 10.07$, $MS_e = .012$, $p < 0.001$, and a marginal effect of trials, $F(1, 25) = 4.12$, $MS_e = .014$, $p = 0.05$; the interaction did not approach significance, $F < 1$. Thus, on the immediate trial subjects were more likely to produce lists from the critical than the neutral lists, reflecting priming effects of the material presented to them during surgery. Priming of similar magnitude was observed on the delayed trial, although this long-term effect may well reflect a carryover from the immediate memory test, rather than priming from the surgical presentation itself.

The patients' free-association performance was analyzed further in a 2 × 2 × 2 mixed-design ANOVA, with test order added as a between-groups variable. While there were no significant main effects or interactions involving test order, the three-way interaction closely approached conventional standards, $F(1, 23) = 4.09$, $MS_e = .006$, $p < .06$. Inspection of the table of means showed substantial priming on the immediate test only when the free-association test preceded the tests of recall and recognition; on the delayed test, both orders showed evidence of priming.

The magnitude of the priming effect, while highly significant, was relatively small: For all patients on trial 1, an average difference of 5.6% between critical and neutral targets. Nevertheless, priming after surgical anesthesia, as evidenced by an advantage of at least one item for critical over neutral targets, was shown by 17 patients (68%) on the immediate trial, and 15 patients (60%) on the delayed trial. Of the 13 patients who received the free-association test before free and cued recall, 11 (85%) gave evidence of priming on the immediate test; of the 12 patients who received the other test order, only 6 (50%) showed priming.

The extent of priming observed was not significantly correlated with the duration of list presentation (immediate trial, $r = .06$; delayed trial, $r = .03$), nor with patient age, sex, body weight, ASA status, time in surgery, or actual end-tidal concentration of isoflurane (all $|r| < .26$, all $p > .05$).

DISCUSSION

This study documented a dissociation between explicit and implicit memory following surgical anesthesia.[1] Adequately anesthetized patients showed no explicit memory for paired associates presented during their surgery, as measured by tests of free recall, cued recall, and recognition. However, a majority of patients did display implicit memory for the same material, as evidenced by a priming effect of the surgical experience on a subsequent word-association task. More priming was shown when the free-association test was administered first, rather than after tests of free and cued recall, suggesting that performance on the explicit memory tests somehow interfered with performance on the implicit test.

The main effect of trials on free-association performance indicates that subjects were more likely to produce items from both critical and neutral targets on the delayed trial compared to the immediate one. Perhaps the subjects were not fully recovered from anesthesia at the time of testing in the recovery room, and this suppressed their performance on the immediate trial. Adam (1979) has shown that subanesthetic doses of anesthetic agents impair performance on a wide variety of cognitive tests. In addition, there may have been some clouding of consciousness due to the postoperative administration of morphine.

The priming results reported here lend support to other recent studies of cognition and anesthesia employing implicit memory paradigms (Ghoneim, Block, Sum Ping, Ali, & Hoffman, 1990; Roorda-Hrdlickova, Wolters, Bonke, & Phaf, 1990; Stolzy et al., 1989). However, in contrast to some other demonstrations (Bennett et al., 1985), which apparently obtained large effects in relatively few patients, the present study obtained a relatively small effect in a majority of patients. Apparently some information can be encoded, to at least some degree, during adequate anesthesia, even though memories for surgical events are not subsequently accessible to conscious retrieval. This line of research offers a new perspective on the conditions under which implicit memories are formed and expressed. For example, priming of old, pre-existing knowledge appears to occur relatively automatically, while implicit memory for new associations requires active processing at the time of encoding (Schacter & Graf, 1986; Schacter & McGlynn, 1989). Previous studies have shown that implicit memory for familiar words (Graf & Mandler, 1984; Jacoby & Dallas, 1981) and associations (Schacter & McGlynn, 1989) is robust following nonsemantic encoding tasks that do not involve elaborative processing. Our results extend these findings by indicating that such priming effects can be observed even when conscious processing of target materials is diminished or precluded by general anesthesia.

The present study involved priming of old knowledge, and it will be interesting whether implicit memory for new associations shows the same effects. Moreover, preliminary findings of other investigators suggest that while some anesthetic regimes produce dissociations between explicit and implicit memory, others impair both equally (Stolzy et al., 1989). For example, the unsuccessful study by Eich et al. (1985) employed a wide variety of anesthetic agents—including, for many patients, benzodiazepine or narcotic premedication and a mixture of nitrous oxide and oxygen accompanying the inhalant. By contrast, the present study employed neither sedative premedications nor nitrous oxide. Since various anesthetic agents probably have different effects on brain function, comparative studies of the cognitive effects of various classes of anesthetic agents may prove informative about the

1. The effects of adequate anesthesia on free recall, cued recall, recognition, and priming in free association were confirmed in analyses of data derived from the immediate trial for all 29 subjects. Thus, a 2 × 2 mixed-design ANOVA with one between-groups factor (test order) and one within-subjects factor (critical vs. neutral targets) for the free association test yielded a significant main effect of targets (mean percentage elicited: critical, 60.0%; neutral, 54.9%), $F(1, 27) = 5.2$, $MS_e = .007$, $p < .05$. The interaction of targets with test order approached significance, $p < .10$. More subjects showed priming when the free-association test was first (12/15 subjects, or 80%), than when it followed free and cued recall (7 of 14 subjects, or 50%).

biological basis of memory and consciousness.

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