Deficits in Recall Following Partial and Complete Commissurotomy

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There have been reports in the literature of both impaired (Zaidel and Sperry, 1974) and intact (LeDoux et al., 1977) memory performance following callosotomy. In the present article, memory is examined in patients who received either partial or complete callosotomy in an effort to determine (1) if there is a memory deficit following callosotomy, (2) if certain types of callosotomy are more likely to lead to a deficit (i.e., anterior vs posterior), and (3) if there is a global memory deficit or if some mnemonic functions are affected more than others. Patients receiving either partial or complete section of the corpus callosum were examined pre- and postoperatively on standardized memory tests and tests of recall and recognition. In addition, two patients with complete callosotomy and matched control subjects were given tests of verbal recall and recognition. A deficit in both visual and verbal recall was found in patients with posterior section, but not those receiving anterior section. No impairment was found on tests of verbal recognition for any patients. Posterior callosal section generally includes the hippocampal commissure and other hippocampal connections, while anterior sectioning does not. Given the known importance of the hippocampus (Milner, 1970) and the differences between recall and recognition memory (Bransford and Johnson, 1972) in normal memory functioning, several hypotheses are proposed as to why these results might be expected.

The neocortex possesses certain specialized functions, such as those associated with language, inference making, facial recognition, timber perception, and several other capacities (see Milner, 1975; Gazzaniga, 1989). Given the importance of the structure for human mental activities, it might be expected that dividing the brain and thereby disconnecting one half of the cortex from the other would impact on a host of cognitive processes, such as overall intelligence and memory, yet at least at the level of clinical observation, separating one half of the neocortex from the other appears to have little impact on overall cognition. Verbal IQ remains intact, as do within-hemisphere reaction times to perceptual stimuli and general problem-solving capacity (Nass and Gazzaniga, 1987). Patients' affect and sense of self are also normal.

There are, however, some clinical observations of negative effects of splitting the brain, although these findings are not conclusive. Zaidel and Sperry (1974) report that standardized memory tests administered postoperatively to patients with section of both the corpus callosum and anterior commissure point to deficits in memory capacity. Other reports suggest normal memory functioning following callosotomy (LeDoux et al., 1977; Sass et al., 1988). In the present article we examine memory performance in patients with partial and complete callosotomy in an effort to determine if there is a memory deficit following callosotomy and, if so, when it occurs and what types of mnemonic functions are affected. There may be critical regions of the interhemispheric commissure system contributing to normal memory function. In particular, split brain surgery involving the posterior regions of the callosum always involves the hippocampal commissure, whereas anterior section of the callosum spares the hippocampal commissure. Inasmuch as the hippocampus has been implicated as essential to long-term memory (Milner, 1970; Squire, 1986), damage to the hippocampal commissure and other callosal fibers connecting the hippocampi that occurs with posterior section of the callosum might be expected to have a detrimental effect on memory. In short, if some mnemonic functions involve the integration of the memory systems in the two hemispheres, damage to the connections between the hippocampi should produce measurable deficits. At least one study suggests that this is the case. In a review of the research on memory and commissurotomy, Clark and Geffen (1989) found that there is no apparent memory deficit in commissurotomy patients unless the patient received hippocampal commissurotomy or some kind of extracallosal damage.

Two methods will be used to examine the effect that damage to the posterior callosum and hippocampal commissure may have on memory functioning. The first is to compare pre- and postoperative memory performance of patients receiving anterior section of the corpus callosum and those receiving posterior section. The second method is to compare memory performance of patients with complete commissurotomies with control subjects.

Materials and Methods

Subjects

Case D.R. (See Fig. 1*b* for MRI postsurgery) is a 39-year-old right-handed female of above-average intelligence. Her callosal section was performed in one operation, and at the time of her surgery, it was decided not to section a small part of the rostrum (see Baynes et al., 1991).

Cases E.B. (Fig. 1*d*), J.J. (MRI not available at time of test), E.S. (MRI not available at time of test), G.M. (Fig. 1*e*), and S.C. (Fig. 1*f*) have all undergone staged surgical sections of the corpus callosum. Case E.B., a 23-year-old female, underwent partial callosal section of intractable epilepsy in 1983. The posterior one-half of the callosum was sectioned in one operation, and the extent of the section was verified with MRI. Prior to callosal surgery, she had undergone a right occipital resection in an effort to control her epilepsy. This resulted in a left hemianopia that has remained static. Because of the preoperative hemianopia, interfield tests of tactile function were carried out. These tests revealed that she was unable to name objects placed out of view when palpated with the left hand, but could name those palpated with the right hand. She was also unable to transfer stereognostic information from one hand to another, thereby demonstrating that no tactile sensory information could be cross-communicated between the two hemispheres. Additionally, while her left hand was able to retrieve like objects in a match-to-sample paradigm, she could not retrieve objects to verbal command with the left hand. The rest of her neurologic history is unremarkable and she currently enjoys good health. Her preoperative memory testing was carried out after her earlier occipital lobe resection and just prior to her callosal section.

Cases J.J. and E.S. were operated on in two stages. Case E.S., a 27-year-old right-handed male, underwent anterior section of the corpus callosum followed 15 months later with posterior section. He is of average intelligence. Case J.J., a 23-year-old right-handed female, also underwent staged surgery with the anterior callosum being sectioned approximately 9 months prior to the posterior section.

Cases G.M. and S.C. underwent anterior section of the corpus callosum only. Case G.M., a 28-year-old left-handed male, is of average intelligence and underwent section of the anterior two-thirds of the callosum. Case S.C., a 27-year-old male of above-average intelligence, underwent section of the anterior two-thirds of the callosum.

Cases J.W. (Fig. 1*a*) and V.P. (Fig. 1*c*) are fully sectioned callosal patients with MRI-confirmed lesions. J.W.'s lesion was complete, while V.P. has fibers remaining in both the splenium and rostrum. Both J.W. and V.P. have been studied extensively over the past 9 years on a variety of perceptual, cognitive, and attentional tests (see Gazzaniga, 1987).

Two control subjects matched to J.W. and V.P. for age and level of education also participated in this experiment. These subjects had a mean age of 39.5 years and a mean of 12.5 years of education.

Procedure

Two types of pre- and postoperative testing were carried out. Six patients (two receiving posterior sectioning, D.R. and E.B., and four receiving anterior sectioning, E.S., S.C., J.J., and G.M.) were given the Russell Revision of the Weschler Memory Scale, which consists of the logical memory and the picture reproduction subtests. The logical memory test involves the recall of two brief stories. The picture reproduction test involves the reproduction of three line drawings, each presented for 10 sec. Scoring for the Russell Revision differed from the Weschler Memory Scale only for the logical memory subtest in that occasionally half points are given when an idea from the story is partially, but not completely, mentioned. In both tests the subjects were tested at two retention intervals. In the immediate condition, subjects were asked to recall the information immediately after presentation. In the delayed recall condition, subjects were asked to recall the information approximately 30 min after presentation. These tests were carried out over several years, and some of the subjects received alternative forms of the same tests. Specifically a few of the pictures that case S.C. received on his postoperative test differed from those other patients received. These pictures were scored using the same scale as the original pictures. In addition, case D.R. did not receive the delayed recall test.

Two of the anterior-sectioned patients (S.C. and G.M.) were also given tests of free recall and recognition both pre- and postoperatively. Eight lists consisting of 40 words each were constructed. The words contained one or two syllables and had an average frequency of 20 occurrences per million (Kucera and Francis, 1967). Half the words in each list were selected as distractors in a two-item forced-choice recognition test. The other 20 words served as targets.

Cases S.C. and G.M. received the eight lists in separate experimental sessions. Four of the lists were given preoperatively and four were given postoperatively. The procedure was the same both pre- and postoperatively. In each session, subjects were told that they would see the list and should memorize the

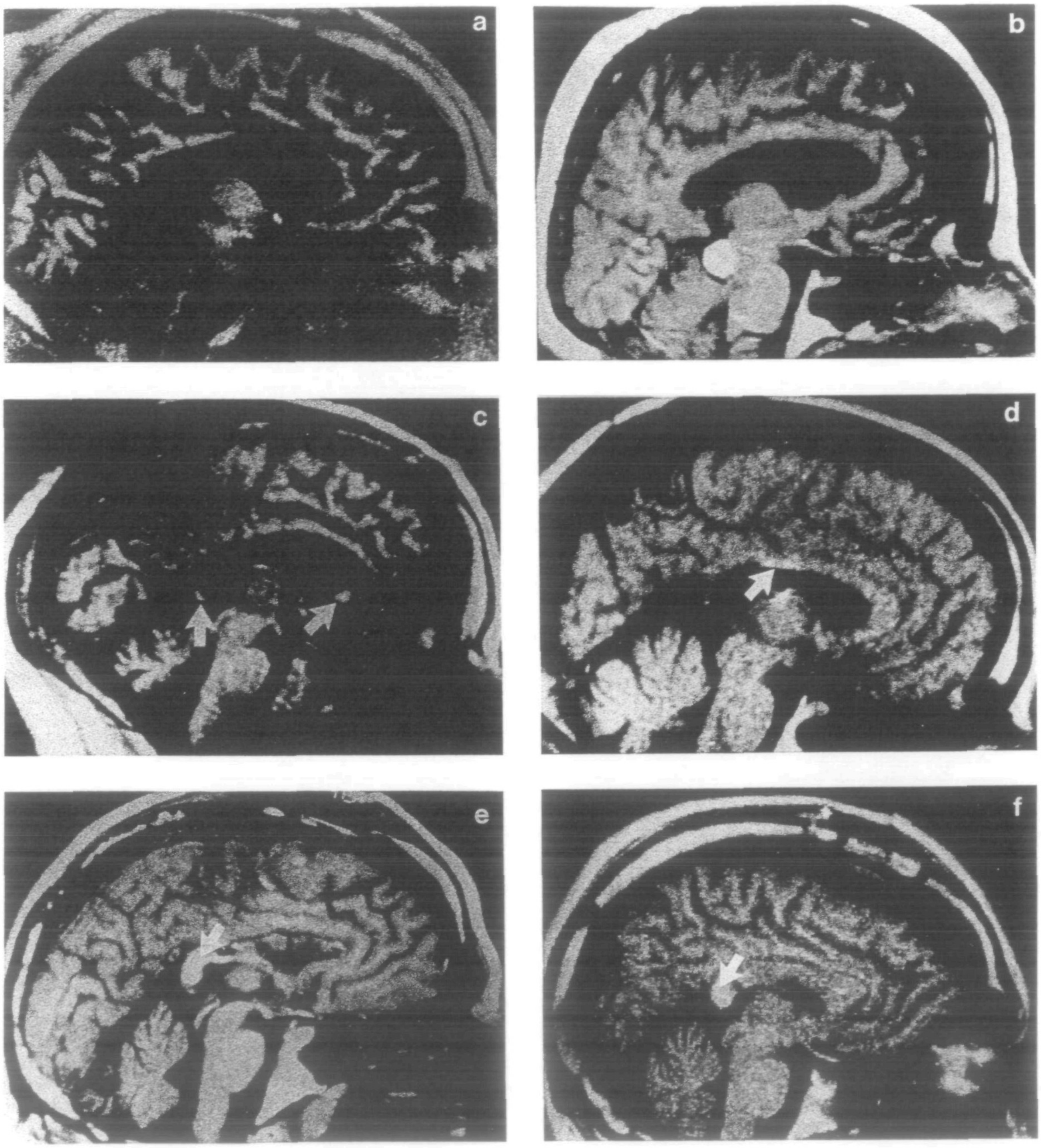

Figure 1. Midsaggital MRI scans of six of the eight patients who underwent either partial or complete callosotomy. Case J.W. (*a*) is fully sectioned. Case D.R. (*b*) has a small bundle of fibers in the rostrum. Case V.P. (*c*) has slight sparing in the splenium and rostrum. Case E.B. (*d*) had only the posterior one-half sectioned, while case G.B. (*e*) and case S.C. (*f*) underwent section of the anterior two-thirds of the callosum. *Arrows: c,* remaining fibers in the splenium and rostrum; *d,* midpoint of callosal section; *e* and *f,* remaining splenium.

list so that they could recall it later. The words were typed on index cards, one word per card, and were presented one at a time at a rate of 5 sec per card. Subjects were then tested immediately, with a 30 sec or 2 min delay filled with arithmetic problems, or a 2 hr delay filled with other standardized tests or conversation. After the delay, subjects were first asked to recall as many words as they could from the studied list. The subjects were given as much time as needed for recall (always less than 3 min) and were encouraged to guess. Subjects were then given a two-item forced-choice recognition test. Subjects were asked to indicate which of two words presented on an index card had appeared in the studied list. One list was randomly assigned to each retention interval since a completely counterbalanced design was impossible given the limited availability of subjects.

Finally, two subjects with complete callosotomy (J.W. and V.P.) and their matched control subjects were given postoperative tests of free recall and recognition. An additional eight recall and recognition lists were constructed in a same manner described above. These lists were presented to the subjects in two separate experimental sessions (four in each session). The presentation and test procedures for these lists are the same as those described above with the

Table 1
Scores for the logical memory (LM) and picture reproduction (PR) subtests of the Weschler Memory Scale tested immediately (Imm) and after a 30 min delay

	Preoperative				Postoperative			
	LM		PR		LM		PR	
Patient	Imm	Delay	Imm	Delay	Imm	Delay	Imm	Delay[a]
Anterior-sectioned patients								
E.S.	8.75	2.75	5	4	6.50	1.50	4	2
J.J.	7.75	4.75	7	4	7.75	5.25	7	8
G.M.	8.25	8.25	8	8	8.50	7.00	11	8
S.C.	6.00	3.50	12	10	6.50	4.00	13	9
Posterior-sectioned patients								
E.B.	9.00	6.25	6	4	7.25	4.75	3	1
D.R.	18.0	—	12	—	9.00	—	6	—

[a] Lezak (1983) reports the mean immediate score for 53 normal subjects between 30 and 39 years of age—logical memory: $\bar{X} = 7.99$, SD = 2.95; picture reproduction; $\bar{X} = 10.09$, SD = 3.01.

exception that the retention interval was always 10 min and was filled with other experiments and conversation.

Results

Table 1 contains the pre- and postoperative individual scores for the logical memory and picture reproduction subtests of the Weschler Memory Scale along with the population norms, and Figure 2 contains the mean scores. As can be readily observed, the full callosal section patient D.R. and the posterior-sectioned patient E.B. show a dramatic decline in performance from preoperative testing to postoperative testing for both verbal and visual stimuli, whereas the anterior-sectioned patients did not show any appreciable decrement in performance. Given the few data points, it was not feasible to do an ANOVA, so separate sign tests were used to compare pre- and postoperative performance for the posterior- and anterior-sectioned patients. The difference between pre- and postoperative performance was found to be significant for the posterior-sectioned patients using a sign test ($p < 0.05$; $N = 6$), but no significant difference was found between pre- and postoperative scores for the anterior-sectioned patients ($p > 0.05$; $N = 16$).

Although the results seem clear for the picture reproduction subtest in that the posterior-sectioned patients show a decrease not found in anterior-sectioned patients, the results for the logical memory subtest are more difficult to interpret for two reasons. First, for case D.R., the preoperative score on the logical memory test was very high (as one might expect from her verbal IQ of 124), so the postoperative decline only managed to bring the scores in line with both the pre- and postoperative scores of the anterior-sectioned patients. D.R. was also given the other subtests of the Weschler Memory Scale, and a significant decline between pre- and postoperative scores was found only on the verbal paired-associate test, which also involves long-term memory (12 preoperatively vs 6 postoperatively). On the orientation (pre, 5; post, 6), mental control (pre, 5; post, 4), and digit span (pre, 8; post, 12) subtests, there was no appreciable difference. Second, a closer look at the individual data reveals that one anterior-sectioned patient, E.S., did show consistently worse performance postoperatively. This performance decline was enough in the logical memory subtest to produce in the anterior-sectioned patients' performance the slight decline in the mean scores. Inasmuch as commissurotomies are inexact, it may be that patient E.S. received more posterior sectioning than anticipated.

Given that the results for verbal recall on the logical memory test are not as clear as one would hope, it is especially significant that recall and recognition performance did not decline postoperatively for the two anterior-sectioned patients, G.M. and S.C. Indeed, as outlined in Table 2, postoperative performance was slightly improved over preoperative performance. This improvement may reflect the reduction in epileptic activity following surgery. These results are clearest for the recall test at all delays where scores postoperatively were found to be significantly better than scores preoperatively using a sign test ($p < 0.05$; $N = 8$). No significant difference was found between pre- and postoperative recognition performance using a sign test ($p > 0.05$; $N = 8$), although this might reflect a ceiling effect. Even after a 2 hr delay, both patients were recognizing items at least at the 95% level. For G.M., performance at the 2 hr preoperative recognition test may have been below ceiling, but overall, both subjects did remarkably well on the recognition test. This suggests that even though the results are somewhat ambiguous for the logical memory subtest, there does not appear to be any postoperative decline in the verbal memory tests of recall and recognition following anterior sectioning of the callosum.

When these results are combined with those of the visual reproduction and logical memory subtests, a consistent pattern emerges. Anterior-sectioned patients show no decrement, and in some cases improvement, in memory following surgery, whereas posterior-sectioned patients demonstrate a marked decline in both visual and verbal recall following surgery.

Given that the posterior-sectioned patients show a memory deficit, one would want to know what kind

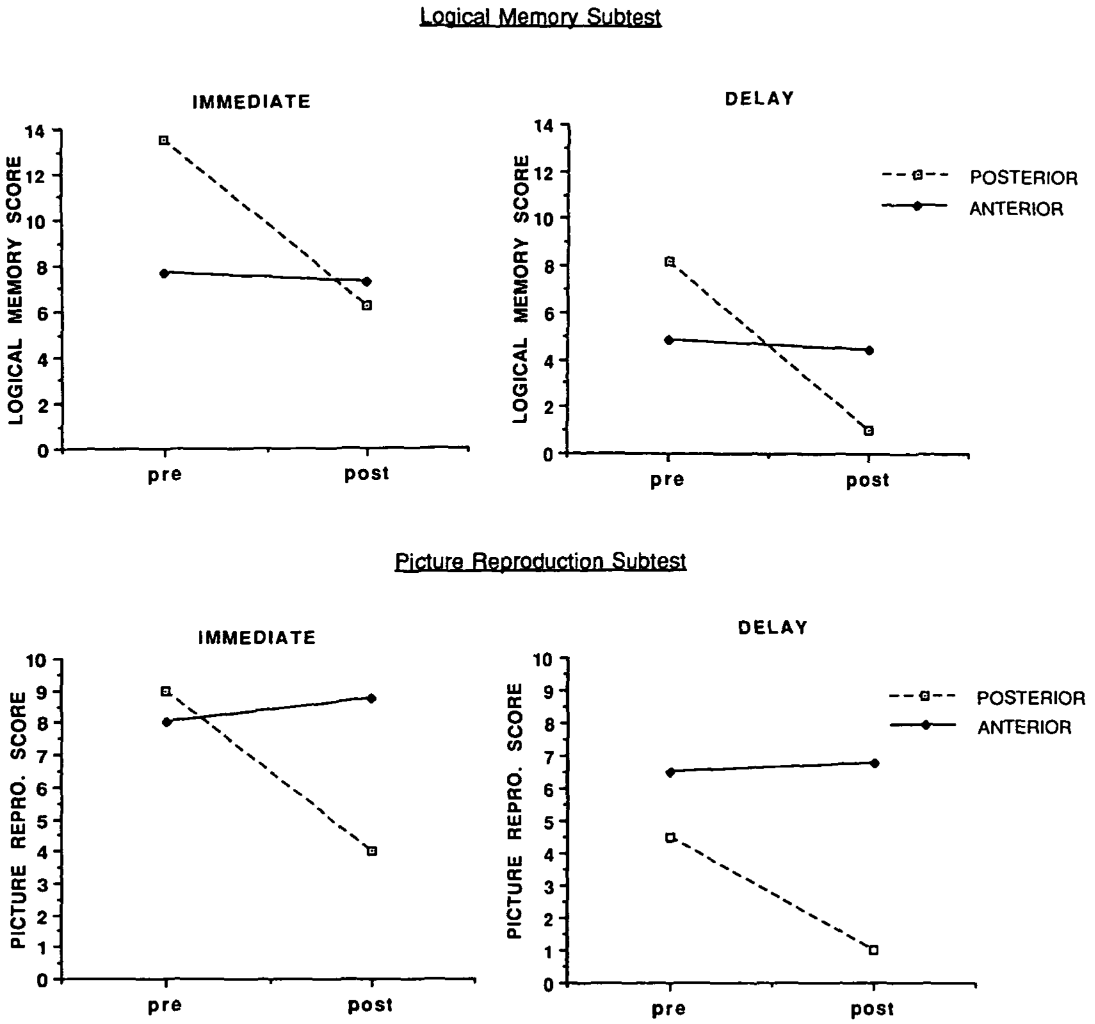

Figure 2. Mean and pre- and postoperative scores for patients receiving posterior and anterior callosal sectioning on the logical memory and picture reproduction subtests, immediate and delay conditions.

of memory deficit it is. It is possible that there is a global memory deficit or it may be that some mnemonic processes are more affected than others when integrative functions are disrupted through posterior and hippocampal commissurotomy. The results of the recall and recognition tests on the complete split-brain patients and matched controls address this issue and can be seen in Figure 3. The split-brain patients have a mean recall score of 1.4 words out of twenty with a standard deviation of 1.3. Their mean recognition score was 17.0 out of a possible 20 with an SD of 2.5. The mean recall score for the control subjects was 5.4 words with an SD of 1.8. Their mean recognition score was 17.9 with an SD of 1.54.

Separate ANOVAs were carried out for each subject and his or her matched control. For V.P., there were significant main effects for type of test [$F(1,14) = 348.9$; MSe = 4.14; $p < 0.01$] and subject [$F(1,14) = 931.6$; MSe = 1.66; $p < 0.05$]. There was not a significant subject by type of test interaction [$F(1,14) = 1.69$; MSe = 4.14; $p > 0.05$]. Given the results, it was decided to perform an analysis of simple effects, which revealed that the control subject performed significantly better on tests of recall [$F(1,14) = 7.8$; MSe = 6.27; $p < 0.01$], but there was no significant difference on tests of recognition [$F(1,14) = 3.50$; MSe = 3.02; $p < 0.05$].

The results for subject J.W. were similar. There were significant main effects for type of test [$F(1,14) = 900.5$; MSe = 1.9; $p < 0.01$] and for subject [$F(1,14) = 6.48$; MSe = 6.25; $p < 0.05$]. There was also a significant subject × type of test interaction [$F(1,14) = 18.9$; MSe = 1.91; $p < 0.01$] An analysis of simple effects revealed that the control subject performed significantly better on tests of recall [$F(1,14) = 29.9$; MSe = 2.56; $p < 0.01$], but not on tests of recognition [$F(1,14) = 0.02$; MSe = 5.6; NS].

These results for cases J.W. and V.P. suggest that the memory impairment found following posterior and hippocampal callosotomy may be specific to some mnemonic processes and not to others; in particular, free recall seems to be more affected than recognition.

Discussion

The present results support two conclusions: (1) there is a memory deficit following callosotomy, if the posterior section is included; and (2) this memory deficit for patients receiving posterior callosotomy is more

Table 2
Recall and forced-choice recognition performance on a 20-word list with retention intervals of 0 sec, 30 sec, 2 min, and 2 hr

	Preoperative				Postoperative			
Patient	0 sec	30 sec	2 min	2 hr	0 sec	30 sec	2 min	2 hr
G.M.	8/19	4/18	8/20	0/16	12/19	9/20	10/19	1/19
S.C.	6/20	6/20	2/20	0/20	7/20	11/20	7/20	7/20

Tests were given pre- and postoperatively. Scores are given as recall score followed by the recognition score, that is, recall/recognition.

evident in some mnemonic functions than others; specifically, recall is more affected than recognition.

Reports of the presence (Zaidel and Sperry, 1974) and absence (LeDoux et al., 1977; Sass et al., 1988) of a memory deficit following callosotomy left the issue unresolved until the recent review by Clark and Geffen (1989) suggested that there was a deficit for some, but not all, callosotomy patients. Specifically, they suggested that those patients with damage to the hippocampal commissure or other extracallosal structures display a memory deficit whereas others do not. The present finding of deficits in both verbal and visual recall following posterior callosotomy is consistent with this conclusion since the hippocampal commissure is damaged during posterior, but not anterior, sectioning of the callosum.

While the present results do not provide any direct support that it is damage to the hippocampal commissure that causes the memory impairment and not other structures affected by posterior callosotomy, one might suspect this is the case given the established role that the hippocampus plays in memory. At least one study (Guenaire and Delacour, 1983) has found that damage to the hippocampal commissure can affect learning performance in rats. It is also possible, however, that other posterior callosal connections are important in normal memory functioning and/or that the hippocampi are connected by posterior callosal projections as well as the hippocampal commissure. The present results do not address these issues. In a study of interhemispheric connections in the temporal lobe of macaques (Demeter et al., 1990), only some hippocampal structures were found to be connected by the hippocampal commissure whereas others had callosal connections. Given this, it is difficult to assess which interhemispheric connections damaged in posterior callosotomy may lead to a deficit in recall.

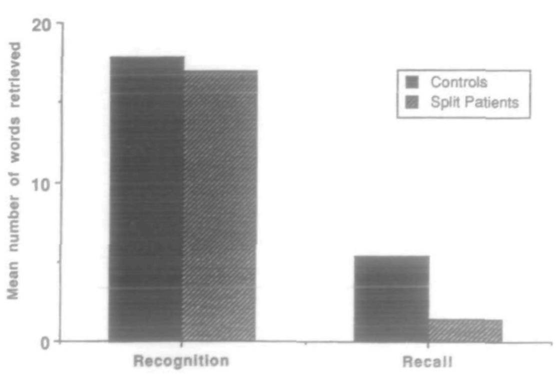

Figure 3. Mean number of words correctly recognized or recalled by split-brain patients and control subjects after a 10 min delay.

The differential effects that anterior and posterior sectioning have on memory suggest that the posterior sectioning disrupts at least some of the mechanisms underlying memory whereas anterior sectioning leaves the memory system relatively intact. Specifying the nature of these mechanisms is difficult, although from the present results one can conclude that disrupting these mechanisms impairs recall performance more than recognition. Given what is known about the differences between recall and recognition memory in normal subjects, one could hypothesize as to why simply disrupting the mechanism of communication between the hippocampi would have more of an effect on recall performance. Recall memory is known to be more sensitive than recognition memory to the multiple representation of events (i.e., dual encoding; Paivio, 1971) as well as elaboration and organization of the to-be-remembered stimuli (Bransford and Johnson, 1972). If the two hemispheres have different mnemonic representations and processing mechanisms, one could imagine that disconnecting the communication between these representations and processes would have a detrimental effect on recall performance. There is evidence that the right and left hemispheres not only represent information in different forms (Milner, 1975), but also have different organizational techniques for to-be-remembered stimuli (Phelps and Gazzaniga, 1991). Although there may be other mnemonic mechanisms disrupted with posterior callosotomy, it is plausible that simply the lack of integrative functioning between the hippocampi would lead to the kind of deficit seen, that is, one in which recall is affected more than recognition.

There are several unresolved issues related to the memory impairment following callosotomy. The present findings, however, provide some empirical insight into the situations in which a deficit might occur, as well as the kind of deficit that emerges. Several hypotheses are proposed as to why one might find a differential deficit of recall memory following posterior callosotomy, but further investigation is needed to clarify the nature of this deficit and to specify which neuroanatomical structures damaged in posterior callosotomy are essential to normal memory functioning.

Notes

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