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Memory for Source after Traumatic Brain Injury

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A fame judgment task was used to distinguish subjects' ability to recognize previously presented information from their ability to recognize the source of that information. Traumatic brain injured (TBI) subjects were impaired relative to controls with respect to verbal recall and recognition as well as memory for source. However, memory for source was demonstrated to be independent of explicit indices of recall and recognition ability. It was also found to be an extremely sensitive index of coma duration in the TBI subjects. The anticipated relationship between source memory and a putative index of frontal function (Wisconsin Card Sorting Test) was modest relative to the relationship between source memory and subjects' performance on a complex visual pattern matching task (Benton Facial Recognition), raising questions about hypothesized cognitive and neurophysiological mechanisms underlying memory for source.

A disruption in memory for source, often referred to as source amnesia (Evans & Thorn, 1966; Schacter, Harbluk, & McLachlan, 1984), refers to the phenomenon whereby individuals have access to information learned during some prior experience but seem impaired in their ability to report

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when or where that information was initially encountered. Amnesics with frontal damage, when tested after very brief retention intervals, tend to produce a higher proportion of source error relative to the amount of information they are able to retrieve (Schacter *et al.*, 1984; Shimamura & Squire, 1987). Also, nonamnesic patients with documented frontal lobe damage have been shown to perform normally on traditional tests of recall and recognition but produce a significantly higher proportion of source error (Janowsky, Shimamura, & Squire, 1989). Within-group analyses have demonstrated a relationship between the degree of source error and performance on tasks considered to tap frontal lobe function (Craik, Morris, Morris, & Loewen, 1990; Dywan & Jacoby, 1990; Schacter *et al.*, 1984). Older adults who are considered more at risk for developmental changes involving the functioning of the frontal lobes show higher rates of source error than younger adults (e.g., Burke & Light, 1981; Cohen & Falkner, 1989; Craik *et al.*, 1990; Dywan & Jacoby, 1990; Hashtroudi, Johnson, & Chrosniak, 1989; McIntyre & Craik, 1987).

While memory for source has been examined in a number of populations at risk for frontal damage, there has been little investigation of this phenomenon in those who have suffered traumatic brain injury (TBI). Investigations assessing neuropathological effects of closed head injury have shown that, irrespective of site of original impact, there is characteristically diffuse generalized damage with superimposed focal damage to frontal polar and anterior temporal areas (Adams, 1975). Neurohistological evidence indicates that the areas of cortex most predisposed to contusion are the frontal poles, the orbital gyri, cortex adjacent to the Sylvian fissure, and the inferior and lateral surfaces of the temporal lobes. The distribution of contusion has been linked to the proximity of these areas to the sphenoidal ridges and bony protrusions on the base of the skull (Adams, 1975; Bigler, 1990). Therefore, irrespective of the variability associated with TBI, the likelihood of frontal damage is high and the behavioral sequelae related to frontal damage is typically observed in this population.

Severity of initial impact is another source of variability within the TBI population. Duration of coma has been proposed as an index of severity (Teasdale & Jennett, 1974) and as a critical determinant of the recovery of intellectual functions (Jennett, Teasdale, & Knill-Jones, 1975; Levin, 1985). However, Trexler and Zappala (1988) found that severity, as measured by coma duration, was a very poor predictor of attentional disorder. This may be due to the inadequacy of coma duration as an index of severity (see Fantie & Kolb, 1991) or to the insensitivity of the measures used to detect long-term dysfunction (Varney & Shepherd, 1991).

It is interesting to note that Jetter, Poser, Freeman, and Markowitsch (1986) found, in their sample of primarily TBI subjects, that memory performance was relatively normal after a short delay. However, after 24 hr, their recognition and cued recall performance remained normal but their free recall was markedly impaired. Such deficits would have been missed in a typical neuropsychological assessment, but might, nonetheless, interfere with performance in work and social settings. Should deficits in memory for source prove to be a subtle but specific impairment linked to frontal lobe dysfunction, they are likely to form part of the sequelae of TBI and should be specifically examined in this population.

Theoretical Perspectives on Memory for Source

This decline in the ability to access episodic or incidental aspects of experience has been described as the impairment of a specific memory system specialized with respect to spatiotemporal information (Schacter, 1987). Shimamura and Squire (1987) suggest that frontal lobe dysfunction causes a disconnection between fact memory and context memory, rather than causing amnesia for the context itself. Moscovitch (1989) links the concept of source amnesia to the phenomenon of confabulation, which would not constitute a problem with a particular kind of memory, per se, but as a problem with the strategic aspects of retrieval. We (Dywan & Jacoby, 1990; Jacoby, Kelley, & Dywan, 1989) have argued that source errors represent an attributional problem resulting from disordered attention.

Whether one sees the underlying deficit as primarily mnemonic, strategic, or attentional, there is considerable agreement that it involves some form of frontally based dysfunction. Even so, the relationships between source error and other indices of frontal involvement are not always as strong as one might expect. For example, some of the amnesics studied by Schacter *et al.* (1984) who, based on the etiology of their amnesia would have had frontal damage, did not show the expected source error. Also, the relationships between source error and frontal tasks in the Shimamura and Squire (1987) sample was positive but failed to reach statistical significance. Craik *et al.* (1990) reported that when they controlled for age within their older sample, the relationship between source errors and frontal measures disappeared. It could be that in older adults, both source error and indices of frontal function were dependent on some other age-related change that we have yet to understand. Thus, while a relationship between source error and frontal function has been documented, the strength of that relationship and the mechanisms underlying that relationship have not been fully explored.

The goals of this study are twofold. First, we would like to determine the degree to which TBI results in memory for source problems and the degree to which these are distinct from the typical disorders of recall and recognition that have been described in this population. While TBI can produce a wide range of cognitive deficits, the mechanics of closed head injury ensures that most subjects will have suffered some degree of frontal lobe damage (Ommaya & Gennarelli, 1974) and should, therefore, be susceptible to source error. The second goal is to further our theoretical understanding of source error by using model testing techniques available through multiple regression to examine the relationship between experimental measures of memory for source and psychometric indices of executive and mnemonic functions.

The Measurement of Source Error

Typically, memory for source has been measured by directly asking people to report the source from which a given item or piece of information was gained. In these paradigms (e.g., Schacter *et al.*, 1984; Shimamura & Squire, 1987) subjects are presented with information that they are not likely to know (arcane facts) or information that they could not know (bogus facts). At test they are asked a series of questions that could be answered on the basis of world knowledge interspersed with other questions that require the recollection of information presented within the experimental situation. When the subject is able to provide an answer they are asked where or when they might have learned it. The time between study and test is varied from minutes for the amnesics to a week for controls in order to equate recall levels.

By instructing people to report source, the researcher is assessing subjects' optimal level of source monitoring, a level that might rarely be achieved when spontaneous monitoring of source is implicitly required as part of some ongoing task. Yet it is this spontaneous monitoring of source that would be critical in guiding everyday behavior. One could also question whether the inability to explicitly recollect source indicates that information about source is not informing judgment. Kelley, Jacoby, and Hollingshead (1989) have demonstrated that implicit information about context does influence judgments about source and this influence can only be countered when explicit alternatives are provided.

In the present study, we examined effects of TBI on spontaneous source monitoring by using a fame judgment task where subjects are asked to indicate whether a particular name is of a famous person (e.g., Dywan & Jacoby, 1990; Jacoby, Kelley, Brown, & Jasechko, 1989; Jacoby, Woloshyn, & Kelley, 1989). The task enables one to measure errors in fame judgment that can occur when experimentally induced familiarity for a nonfamous name is misinterpreted by the subject as familiarity due to real-world fame. To avoid making such source errors, subjects would have to consciously monitor the source of item familiarity. In our study, people were required to read a list of names that they were told were nonfamous. Subjects read the list under the pretense that we were interested in their ability to correctly pronounce names, but the list actually served as a means of increasing the familiarity of certain nonfamous names. Those old nonfamous names were then mixed with new famous and new nonfamous names and presented for fame judgments.

Conscious recollection that a name had been read in the list of nonfamous names was important for the fame judgment task. If a person recollected that a name had been read in the list, the name could be called *nonfamous* with certainty. Without such conscious recollection, previously reading the name was expected to increase its familiarity and make it more likely to be mistakenly called *famous*. That is, reading a name in a list of nonfamous names was expected to have an opposite effect on fame judgments when the source of the familiarity was recollected compared with when it was not recollected. This means that differences in fame judgments of old and new nonfamous names can be used to examine the effects of TBI on an individual's ability to monitor the source of familiarity that attends previously presented events. We expected the subjects in the TBI group to be less likely than those in the control group to spontaneously recollect source and to be more likely than the controls to make familiarity errors by mistakenly calling old nonfamous names famous.

In the present study source errors were defined relative to a constant number of old versus new nonfamous names presented for fame judgments. Also, the number of source errors based on experimentally induced familiarity were residualized by removing variance due to general error rate, i.e., subjects' tendency to call the not previously encountered (new) nonfamous names "famous."

Psychometric Measures

All of the TBI subjects were administered a battery of neuropsychological tests as part of a larger study on the long-term sequelae of TBI and to determine the relationship between source memory as indicated by the famous names task and the clinical measures typically used to monitor the cognitive sequelae of TBI. We were primarily interested in contrasting frontal and posterior functional systems and therefore chose to focus on two measures that have been linked with these areas in the neuropsychology literature. These are the Wisconsin Card Sorting Test (Milner, 1963; Heaton, 1981) and the Benton Facial Recognition Test (Benton, Hamsher, Varney, & Spreen, 1983). We recognize that reciprocal relations in brain function are the rule and are not arguing that performance on a psychometric task can be localized in the strict sense. Nonetheless, the further forward the tissue, the less neural processes are dedicated to the processing of visual information and the more they are involved in integrative and monitoring functions (e.g., Milner and Petrides, 1984; Stuss & Benson, 1986).

Persistent impairments in the Wisconsin Card Sorting Test (WCST) have been documented following excisions to the frontal cortex (Milner, 1963; Drew, 1974; Robinson, Heaton, Lehman, & Stilson, 1980). However, recent evidence (Anderson, Damasio, Jones, & Tranel (1991) suggests that the WCST on its own cannot be used as a definitive indicator of structural damage to the frontal lobes. Nonetheless, in the structurally intact brain, the WCST has been directly related to the integrity of frontal lobe function. Weinberger, Berman, and Zec (1986), using radioactive xenon gas as a tracer of cerebral blood flow, demonstrated that normal control subjects showed a clear increase in level of blood flow in the frontal cortex during the WCST but not during a nonfrontal (number matching) test. As well, we (Segalowitz, Unsal, & Dywan, 1992a) have demonstrated that the Contingent Negative Variation (CNV), a frontally generated event-related potential (see, for example, Fuster, 1987, 1989), is reliably associated with the percentage of perseverative errors made by TBI subjects on the WCST. Similar relationships have been noted for normal adolescents (Segalowitz, Unsal, & Dywan, 1992b), and for normal older adults (Dywan, Segalowitz, & Williamson, 1992). CNV was not related to psychometric tasks less reliant on cognitive flexibility or executive function.

In contrast, the Benton Facial Recognition Test (BFRT), essentially a pattern-matching task, measures visuoperceptual abilities that have been shown to be associated with the functioning of the more posterior areas of the right hemisphere (Benton, 1980, 1985). Visual perception takes place through the activation of networks of cells widely distributed throughout the posterior parietal and inferior temporal regions of the brain (e.g., Desimone & Ungerleider, 1989; Mishkin, Ungerleider, & Macko, 1983) so that a visual matching task would be relatively more dependent on posterior than on frontal functioning. Moreover, Kolb, Milner, and Taylor (1983) found such tasks to be relatively insensitive to frontal lobe dysfunction and we (Segalowitz et al., 1992a,b; Dywan *et al.*, 1992) have not found the BFRT to be related to the frontally based CNV.

The California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987) served as a test of verbal memory. There is a high degree of convergence between the CVLT and the more traditional Wechsler Memory Scale—Revised (WMS—R; Wechsler, 1987). The CVLT, however, provides more information on which to assess learning strategies (Delis, Cullum, Butters, Cairns, & Profitera, 1988).

Thus, we measured the spontaneous use of source memory, using the fame judgment task in a group of subjects who had suffered moderate to severe TBI and a group of normal controls. We obtained psychometric measures of frontal function as has been done by others. However, we also used a control task, the BFRT which is not usually associated with frontal function and the CVLT, a psychometric index of explicit verbal recall ability. We expected that those in the TBI group would be more likely than controls to make familiarity-based errors in the fame judgment task irrespective of any baseline differences in general world knowledge. To confirm the separability of source error from a general decline in memory ability in the TBI group, we would expect that indices of explicit recall would account for little variance in our index of source error but that explicit recall ability would predict how well subjects would recognize previously read nonfamous names when asked to do so directly, i.e., when their attention is drawn to the experimental source of familiarity as opposed to when their attention is drawn to familiarity due to world fame. To fully support the hypothesis linking deficits in memory for source to deficits in frontal functioning, we would expect that our index of source error would be strongly related to subjects' performance on the WCST but only minimally to their performance on the BFRT.

METHOD

Subjects

Subjects were 13 adults (2 women and 11 men), ranging in age from 18 to 42 years (*M* age = 27.1 years) who had suffered traumatic brain injury. Most had been involved in motor vehicle accidents. Time since trauma ranged from 1 to 15 years (*M* = 7.8 years). Medical history was gathered from interviews with subjects and family members and review of available medical records. The range of injury was moderate to severe. Length of coma ranged from 0 to 60 days (*M* = 29 days), post-traumatic amnesia ranged from 0 to 120 days (*M* = 47 days). Preinjury level of education ranged from 10 to 14 years (*M* = 12 years, *SD* = 1.6). At the time of testing three subjects were employed either full or part time, two were in school or taking a course, and the others remained at home. Most required some social or financial support.

Control subjects were 24 university undergraduates (14 women and 10 men), ranging in age from 18 to 24 years (*M* age = 19.5) who served in the experiment for course credit. Mean years of education for the control subjects was 13.1 (*SD* = .41).

Materials

Sixty famous and 80 nonfamous names served as materials for the experiment. The famous names were selected with the criteria that most people would recognize the name as famous but would probably be unable to specify what the named person did to attain fame. The famous names were correctly identified as famous by 60 to 70% of both young and older adults who had participated in pilot testing and in earlier studies using the same paradigm. The use of famous names for which people were generally unable to specify the achievement of the named person was meant to make people reliant on the familiarity of famous names when making fame judgments. Examples of famous names are Roger Bannister, Minnie Pearl, and Christopher Wren. Nonfamous names were constructed to match with the famous names on the following characteristics: length of first and last names; sex, indicated by the first name; and the nationality of origin of the last name. Examples of nonfamous names are Sebastian Weisdorf, Valerie Marsh, and Adrian Marr.

The famous and nonfamous names were organized into three list formats so that across formats, each nonfamous name was represented in each possible combination of conditions. For each list of names, the presentation order of names was random, with the restriction that not more than three names of one type (e.g., famous or nonfamous) could be presented before the presentation of one name of the other type.

Procedure

There were four phases to this experiment. In the first phase, subjects were presented with a series of famous and nonfamous names and were asked to make fame judgments. These data provided a baseline for subjects' ability to discriminate between the types of names. In the second phase, subjects were asked to read a series of nonfamous names so that these names would seem familiar when encountered in subsequent phases. In the third, or test, phase, subjects were presented with another test of fame judgment. This time, however, some of the nonfamous names were selected from those that had been read in Phase 2, thus requiring subjects to discriminate between the familiarity due to fame and the familiarity due to previous presentation. In the fourth phase, subjects were asked to distinguish between the as-yet-unused names that had been read in Phase 2 and a new set of nonfamous names that served as foils. These data would allow us to compare source memory with simple recognition memory performance. For the first three phases names were presented consecutively by means of an MS-DOS computer with a Zenith CGA monitor.

Phase one. Twenty famous and 20 nonfamous names were presented for a subject-paced test of fame judgment, providing baseline data for each subject with respect to his or her general ability to discriminate between famous and nonfamous names. Although one may think that looking at subjects' ability to distinguish between the new famous and the new nonfamous names presented during Phase 3 might be sufficient to determine baseline levels of discriminability, the possibility existed that the TBI and Control subjects would use different strategies to protect themselves from making familiarity-based errors. Comparing performance on Phase 1 provided an opportunity to assess discriminability and report bias prior to our introducing the potential for source confusion. In this way we would be able to determine whether the TBI or Control subjects responded differentially to the change in task demands that the test phase provided.

When introduced to the fame judgment task, subjects were told that the famous names that were to be presented for test were not names of extremely famous people such as Pierre Trudeau or Marilyn Monroe. Subjects were also told that they would not be asked to describe what a named person had done to become famous. These instructions were meant to encourage subjects to use familiarity as a basis for their fame judgments.

Subjects indicated their fame judgment for each presented name by pressing one of two large keys, a key at their right hand marked *famous* and a key at their left hand marked *nonfamous*. Each decision, as well as the time to make that decision, timed from the onset of the presentation of a name, was recorded by the computer and subjected to a log transformation prior to analysis. After a decision had been made by pressing a key, the name that had been tested disappeared from the screen and was replaced by the message, "Press center key when ready." Pressing the center key resulted in removal of that message from the screen and presentation of the next name in the list for its test. This sequence continued until all names in the list had been presented. None of the names used in Phase 1 were used in subsequent phases of the experiment.

Phase two. Subjects were instructed to read aloud each of 40 nonfamous names presented at a rate of 2 sec per name. Subjects were told that we were interested in the speed and accuracy with which they could pronounce the names and that their pronunciation of names was being recorded. Although a microphone was placed on top of the monitor to make the instructions more credible, neither pronunciations nor latencies were actually recorded.

Subjects were correctly informed that all of the names that were to be presented in this phase of the experiment were nonfamous.

Phase three (test phase). In this phase, subjects were presented with 40 famous and 40 nonfamous names for a test of fame judgments. All of the famous names were new, not presented earlier in the experiment. Of the nonfamous names, 20 were new names and 20 were old names that had been read in the list of nonfamous names. The procedure for the test of fame judgments was the same as that used in the first phase of the experiment, with the exception that subjects were informed that some of the nonfamous names had been presented once before in the experiment and some were new. Thus, recognizing a name as having been read in the list of nonfamous names could not be the sole basis for judging it to be nonfamous.

Phase four. In the final phase of the experiment, a test of list recognition was given. The 20 nonfamous names that had been read during the second phase of the experiment, but that had not been presented for fame judgments in the third phase of the experiment, served as old names for the test of list recognition. Old and new nonfamous names were randomly intermixed and typed on a sheet of paper. Subjects were asked to circle the nonfamous names that they had read in the earlier phase of the experiment.

List formats were constructed such that across formats, each nonfamous name represented each possible combination of conditions. That is, names that served as new nonfamous names presented for fame judgments with one combination of study and test lists (format) served as old nonfamous names in another format, names presented for fame judgments in the first phase in one format were presented in the third phase for fame judgments in another format, and so on. This use of formats ensured that differences among conditions or phases of the experiment could not be due to differences among the particular names that were used.

Additional Neuropsychological Testing

Neuropsychological measures of cognitive functioning included the WCST, the BFRT, and the CVLT. The WCST requires subjects to determine rules for matching cards to a set of four key cards by using the limited feedback ("correct" or "incorrect") provided by the examiner. The cards vary on the dimensions of color, shape, and number and the criterion for a correct sort changes once a set response has been established. The BFRT requires subjects to choose one or more photographs within an array corresponding to a sample photograph of the same individual on an opposite page of the test booklet. Variation in lighting and pose make the distinctions increasingly more difficult. Both the sample and the choices are in full view during the facial recognition task.

To do the CVLT, subjects are presented with a list of 16 words that fall into four taxonomic categories, and they are given five study and five test trials to examine their learning of those words. For each study trial, words are presented in the same order, with words from the different categories being randomly intermixed. This fifth recall trial is followed by a distractor task with subsequent tests of long-term recall and recognition resulting in several scores. However, in this study, we used only the total number of items recalled over the five learning trials as our index of general memory ability.

RESULTS

Group Differences in Accuracy and Criterion Used for Fame Judgments

In the first set of analyses, performance in the baseline phase was compared with that in the test phase to examine any differences in the

TABLE 1
Hit Rate (d') and Report Criterion (β) Values for Traumatic Brain Injured (TBI) and Control Subjects across Three Phases of the Fame Judgment Task

	TBI		Controls	
Phase	d'	β	d'	β
Baseline				
M	1.32	1.90	.99	1.87
SD	.55	1.45	.56	1.22
Test				
M	.93	2.01	.96	1.86
SD	.83	1.13	.62	1.16
Recognition				
M	1.28	1.81	1.94	2.75
SD	.89	1.03	.55	.91

accuracy and in the criterion used for fame judgments. As well as examining the possibility that the groups might differ with respect to their general response criterion at baseline, we were also interested to know whether they would change their criterion between baseline and test. To address these issues, a signal-detection analysis was performed on the data (see Table 1). For that analysis, the probability of correctly identifying a famous name served as the probability of a hit, and the probability of calling a new nonfamous name *famous* served as the probability of a false alarm. With these probabilities, scores of discriminability (d') and response bias (β) were computed and submitted to a 2 × 2 analysis of variance (ANOVA), with group (TBI or Control) as the between-group factor and phase (Baseline or Test) as the within-group factor.

We found no overall difference in baseline discriminability between TBI and Controls ($d' = 1.13$ vs. $d' = .98$), $F(1, 35) = .68$, n.s. An analysis was also performed on subjects' response bias, as indicated by beta values. This analysis failed to reveal any significant effects of group ($\beta = 1.95$ vs. $\beta = 1.87$) for TBI and Controls, respectively, $F(1, 35) = .05$, n.s. In neither case was there a significant interaction between group and phase, indicating that the groups did not alter their discriminability or response criterion differentially as a function of test phase.

We also examined the time subjects took to decide that a name was famous. Decision times are shown in Table 2. Subjects in the TBI group (2547 msec) took longer than Controls (1189 msec) to make correct decisions for famous names, $F(1, 35) = 75.14, p < .001, n^2 = .47$. There was also a group-by-phase interaction, $F(1, 35) = 6.29, p < .02, n^2 = .15$, such that subjects in the TBI group decreased their decision time from baseline to test (2650 msec vs. 2422 msec, respectively), whereas Con-

TABLE 2
Proportion of Names Called Famous (PF) and Time Spent to Make Correct Decisions (DTs) by Type of Name

	Baseline				Test			
	PF		DT(MS)		PF		DT(MS)	
Type of Name	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
TBI								
Famous	.69	.13	2651	745	.60	.10	2443	629
Old nonfamous	—	—	—	—	.25	.22	2563	966
New nonfamous	.27	.21	3179	1600	.27	.28	2670	979
Controls								
Famous	.57	.13	1144	331	.54	.16	1235	339
Old nonfamous	—	—	—	—	.14	.14	1213	289
New nonfamous	.25	.18	1407	576	.25	.22	1355	461

Note. Decision times are for correct decisions only.

trols increased their decision time from baseline to test (1144 msec vs. 1235 msec, respectively). So, although the TBI subjects did not demonstrate a shift in report criterion as measured by the overall ratio of hits to false alarms, effects on decision times can be taken as evidence that Controls reacted to the possibility of confusion among sources of familiarity during the test phase by being slower to correctly decide that a name was famous than they had been during the baseline phase of the experiment. In contrast, subjects in the TBI group decreased their decision time when they were faced with the possibility of confusion among sources of familiarity.

Group Differences in Susceptibility to Familiarity Errors

We expected the subjects in the TBI group to be more likely than those in the control group to mistake the familiarity of an old nonfamous name read earlier for the familiarity due to the name being a famous one. That is, TBI subjects were expected to be more likely to mistakenly respond *famous* to old nonfamous than to new nonfamous names. To test this, the proportion called famous of the 20 old (previously read) nonfamous names was used as the criterion measure in a hierarchical regression analysis. In order to remove variability due to general error rate, the proportion called famous of the 20 new (not previously read) nonfamous names was added on the first step. As expected, subjects' tendency to call new nonfamous names famous (i.e., general error rate) accounted for a significant proportion ($sr^2 = .31$) of variance in subjects' tendency to make familiarity based source errors, $F(1, 34) = 15.98$, $p < .001$. Saving the residualized source error scores derived from this analysis provided us with an index of subjects' tendency to make source error unconfounded by variance due to general error rate.

Residualized source error scores ranged from $-.30$ to $.34$ ($M = 0$, $SD = .15$). These scores do not represent absolute error rate but rather the propensity to call old, relative to new, nonfamous names famous. Thus, a residualized source error score of .34 would indicate that the subject was more likely to call old, as opposed to new, nonfamous names famous (i.e., to make a source error). The higher the source error score, the more likely it is that the subject has misattributed experimentally induced familiarity to extraexperimental sources.

The next question was to determine whether the TBI group was more likely than the controls to make source errors. Using the residualized source error score as the criterion variable and adding Group on the first step of a hierarchical regression analysis indicated that group membership increased the proportion of explained variance by 11%, $F(1, 35) = 4.46$, $p < .05$. Group continued to add significant variance to the prediction of source error even when general levels of discriminability (d' at baseline) or response bias (beta at baseline) were added prior to the group vector. In neither case did the addition of these baseline indices attenuate the relationship between group and source error, nor did they produce any significant interaction with Group when added on the last step of the regression equation.

One might argue that subjects in the TBI group would be less able to recognize the previously presented names and that source error is simply another index of poor memory. To assess this, we examined the relationship between source error and subjects' ability to make accurate recognition judgments in Phase 4 of the experiment. In Phase 4, subjects were presented with the 20 nonfamous names that they had read earlier but that had not been used in the Phase 3 fame judgment task. A signal detection analysis of the probability of a hit versus the probability of a false alarm provided an index (d') of sensitivity to previous occurrence. Those in the TBI group ($d' = 1.28$) were poorer than the controls ($d' = 1.94$) in recognition memory with Group accounting for 19% of the variance in recognition d', $p < .01$. The relationship between recognition d' and source error is negative but unreliable ($r = -.19$, n.s.).

We examined the relationship among variables using regression model testing procedures (Pedhazur, 1982). Adding recognition d' on the first step of a hierarchical regression equation accounted for less than 4% (n.s.) of the variance in source error and did not fully attenuate group differences. Group, entered on the second step, continued to account for 8% of the variance in source, $F(1, 34) = 3.05$, $p = .09$. However, when the order of entry was reversed, so that Group is added on the first step and recognition d' is added on the second, it became clear that subjects' ability to recognize the old nonfamous names, while significantly different between groups, adds no unique variance to the prediction of source error once Group has been accounted for. Thus, while there is shared variance between the group and recognition d' variables, recognition d' is found to add less than 1% unique variance to the prediction of source error when assessed across the entire sample.

Partitioning Variance in Memory for Source

Another approach is to examine variability in source error within the TBI group. In this way, variance in source error is less likely to be confounded by group-related as opposed to task-related factors. We compared subjects' ability to monitor source with their ability to monitor previous occurrence irrespective of source. If source error is simply a function of poor memory, then one should be able to predict one from the other. Also, if both source error and poor recognition are products of generalized cognitive dysfunction, then one should be able to predict both source error and recognition ability from other psychometric indices of impairment.

First, the zero-order correlation indicates that, while in the appropriate direction ($r = -.17$), the ability of TBI subjects to recognize the previously read nonfamous names accounted for less than 3% of the variance in source error (n.s.). So, even within the TBI population, one cannot predict a subject's tendency to make source error simply on the basis of poor recognition for the previously read names.

To answer the second question as to whether both source error and recognition can be predicted on the basis of general impairment levels, we ran two series of hierarchical regression analyses. In the first series we used memory for source as the criterion variable and in the second series we used recognition d' as the criterion variable. In each case we entered the total recall score on the CVLT on the first step. This provided us with an index of how well an individual could learn and retrieve a standard word list. To the degree that both of our criterion variables are dependent on mnemonic functions, the CVLT recall score should be able to predict them both.

On the second step we entered subjects' score on the WCST in order to provide an indication of their frontally based executive abilities. In order to test the specificity of relationships between our psychometric and experimental measures, we examined the BFRT as the third variable. We did not expect that this task of more posteriorly based pattern-matching ability would explain any additional variance in either criterion measure. While some subjects would have parietal damage, this is not usually considered a defining feature of TBI relative to the deficits typically observed in frontal and hippocampal functions, nor should it be as directly linked to source error or to recognition ability. Results of these analyses are as follows.

Source discriminability at test. Using the residualized index of source error as the criterion variable, CVLT entered on the first step accounted for 16% ($F(1, 11) = 2.04$, n.s.) of the variance in source error. Added on the second step was the percentage of perseverative errors subjects made on the WCST. The WCST explained an additional 26% of the variance ($F(1, 10) = 4.5, p = .06$). Thus, our index of frontal function adds somewhat to our ability to predict source error over that which can be explained by CVLT alone. On the third step, we entered the BFRT, our index of more posterior function. The BFRT accounted for an extra 27% of the variance in source error ($F(1, 9) = 7.81, p < .02$) over that explained by the first two measures. The interactions increased the proportion of explained variability in source error by 8% (n.s.). Altogether, we were able to explain 77% of the variance.

The semipartial correlation coefficient squared (Sr^2) was then calculated separately for each independent variable. Sr^2 represents the unique contribution of each dependent variable to source error in the context of the other variables in the equation (Cohen & Cohen, 1983). The results of these analyses are illustrated in Table 3. Relative to other variables in the equation, the CVLT accounted for less than 1% of unique variance in our prediction of source error, the WCST accounted for 15% of unique variance, while the BFRT explained the largest portion (27%) of unique variance in subjects' tendency to make source errors. Since the BFRT is not usually considered an index of frontal lobe function, these results are not strongly supportive of the hypothesis linking memory for source to prefrontal control processes.

Discriminability (d') during recognition. In a second set of analyses, we used, as a criterion variable, a measure of d' based on subjects' explicit recognition of earlier presented names in Phase 4 of the Famous Names Task. This measure provided an index of subjects' sensitivity to previous occurrence. CVLT (our measure of explicit recall ability) was added on the first step of a regression analysis and accounted for 48% of explained variance $F(1, 11) = 10.03, p < .01$). The CVLT continued to account for approximately the same amount of variance in the criterion measure when it was entered at any later point in the regression. WCST entered on the second step increased explained variance by only 3%, $F(1, 10) = .64$, n.s.). The BFRT entered on the third step added another 3%, $F(1, 9) = .51$, n.s., while interactions added another 8% (n.s.) allowing us to account for 62% of the variance in subjects' sensitivity to previous occurrence on the Phase 4 recognition task. Reversing the order of entry did little to change the relative weight of the variables. As can be seen in Table 3, the largest proportion of unique variance was accounted for by verbal recall as measured by the CVLT (50%), with indices of frontal

TABLE 3

Unique Contributions (Sr^2) of CVLT Total Recall, WCST Percentage Perseverative Errors, and BFRT Correct Matches When Regressed against Sensitivity to Previous Occurrence (Recognition d') and Sensitivity to Source (Source Error)

Variables	Sr^2	β	t	Prob.
		Source error (total R^2 = .77)		
CVLT	.00	.08	.36	.73
WCST % perseverative error	.15	.44	2.07	.07
BFRT correct matches	.27	−.61	−2.80	.02
Interactions	.08	—	all < 1.00	n.s.
		Recognition d' (total R^2 = .67)		
CVLT total recall	.50	.85	3.12	.01
WCST % perseverative error	.02	.15	.60	.56
BFRT correct matches	.03	−.19	−.71	.50
Interactions	.14		all < 1.00	n.s.

Note. Sr^2 refers to semipartial correlation when variable is entered on third step of hierarchical multiple regression. Interactions are always entered last. CVLT, California Verbal Learning Test; WCST, Wisconsin Card Sorting Test; BFRT, Benton Facial Recognition Test.

function (WCST = 2%) and posterior function (BFRT = 3%) adding very little unique variance.

Relationship of Source Error to Variance within the TBI Group

Our last question was to see whether we could determine the level of source error among the TBI subjects on the basis of injury-related variables. Ratings were based on interviews with subjects and their families and an examination of hospital records. Length of post-traumatic amnesia, while often considered a useful indicator of severity and recovery (Jennett & Teasdale, 1981) was ambiguously recorded for a number of our subjects. However, we were able, on the basis of medical records, to confirm length of coma on 11 of the 13 subjects. Coma can occur after TBI for a number of physiological reasons, such as edema, irrespective of the location of injury. However, it is more likely to be a sign of brain stem injury than frontal damage *per se* (e.g., Bigler, 1990). That is, one can sustain massive frontal damage without necessarily suffering coma (e.g., Macmillan, 1986). Nonetheless, length of coma has often been used as an index of severity (Teasdale & Jennett, 1974) and as a negative indicator of recovery (Jennett *et al.*, 1975; Levin, 1985; Fantie and Kolb, 1991). We also had enough information from surgeons' reports, CT scan, and MRI data to roughly classify 11 subjects as to whether their injury was primarily frontal or primarily brain stem. Laterality of primary damage varied within these groups but the sample size was too small to divide subjects further on this dimension.

TABLE 4
Zero-Order Correlations between Injury-Related Variables (Coma Duration and Localization) and Cognitive Performance as Indicated by Source Error, Recognition, CVLT, WCST, and BFRT

	Source error	Recognition	CVLT	WCST	BFRT
Coma	.72*	−.18	−.50	.41	−.44
Frontal	.27	−.56	−.49	.48	.04
Brain stem	.20	−.19	−.27	.07	−.02

Note. CVLT, California Verbal Learning Test; WCST, Wisconson Card Sorting Test; BFRT, Benton Facial Recognition Test.
$^*p = .013$.

Table 4 indicates zero-order correlations between these injury-related variables and the experimental and psychometric indices of behavior. The only relationship that reaches statistical significance is between source error and length of coma ($r = .72$, $p < .01$) accounting for 52% of the variance. As Fig. 1 indicates, this is not due to outlier effects. Thus, in this sample, our measure of source memory was more sensitive to the severity of trauma as indicated by length of coma than either memory measure (recognition d' or CVLT total recall) or than subjects' performance on the WCST or the BFRT.

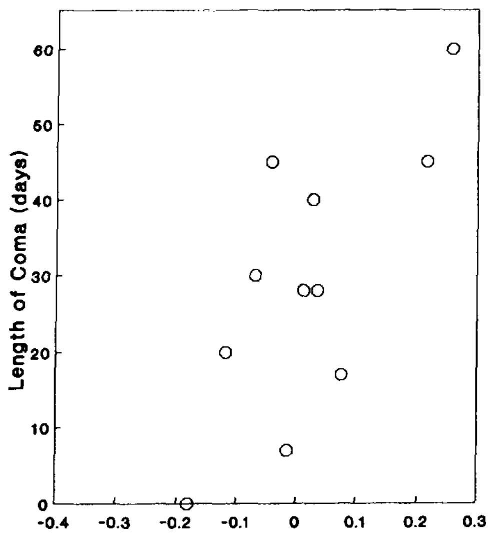

FIG. 1. Scatter plot indicating relationship between source error and length of coma in traumatic brain-injured group.

DISCUSSION

We found that for subjects who had sustained a traumatic brain injury, reading a list of names that they were told were all nonfamous increased the likelihood that those names would be called famous in a subsequent fame judgment task. In contrast, subjects in the control group were more likely to correctly attribute the familiarity of the previously read nonfamous names and were less likely to make this fame judgment error. The subjects in the TBI group made more source errors at test even though they did as well as the control subjects in distinguishing famous from nonfamous names at baseline. Thus, group differences in source error could not be explained by differences in the general ability to discriminate between famous and nonfamous names or by any general bias toward saying "famous" to names during the baseline phase of the experiment. Nor was the difference due to the inability of the subjects in the TBI group to recognize the "familiarized" nonfamous names when directly asked to do so on a subsequent test of simple recognition.

Those in the TBI group did have poorer recognition for the previously read nonfamous names. However, the variance in recognition scores, while to some extent accounting for group membership, did not predict the variability in subjects' tendency to make source errors. For the TBI subjects, our psychometric index of verbal recall (CVLT) accounted for 50% unique variance in their ability to recognize the names they had read earlier. However, the CVLT accounted for less that 1% unique variance in predicting subjects' tendency to make source errors. That is, while subjects did vary in their verbal recall ability, the unique explanatory power of the CVLT in predicting source error was close to zero.

Together, the CVLT, WCST, and BFRT were able to predict 77% of the variance in source error for the TBI subjects. However, subjects' performance on the BFRT (our nonfrontal measure) was the single most powerful predictor of their ability to discriminate between sources of familiarity for nonfamous names accounting for 27% of the unique variance in this prediction. These results suggest that the relationship between memory for source and frontal function may not be straightforward. Nevertheless, source error was the best, most sensitive index of length of coma. It was more sensitive than any of the traditional psychometric measures available for these subjects, including the WCST. Coma is often used to indicate the severity of neural damage. The more serious the injury, the more one would expect damage to brain stem and diencephalic structures (e.g., Gennarelli, 1986). However, as mentioned earlier, Trexler and Zappala (1988) did not find coma duration to be a particularly sensitive predictor of attentional deficit in chronic TBI. We suggest that explicit measures of attention and memory may not be sensitive enough to capture the subtle disorders in attentional control that persist long after the acute phase of recovery. We propose that a clearer understanding of the etiology of source error would lead to a clearer understanding of the cognitive sequelae of TBI.

The Relationship between the BFRT and Memory for Source

The relationship between source error and BFRT has been replicated in a sample of older adults (Dywan *et al.*, 1992). However, because of the multifaceted nature of both tasks, the mechanism responsible for these relationships is not obvious. We see at least three possibilities that could be put to empirical test. First, since higher level integrative functioning within the CNS extends beyond the prefrontal cortex, the physiological basis for source memory may also extend beyond the prefrontal cortex but has not as yet been documented. It is well accepted that the temporal/parietal regions of the brain are involved in tertiary-level integration of sensory stimuli (e.g., Hyvarinen, 1982; Pandya & Yeterian, 1985). According to this model, the prefrontal cortex can be seen as being involved in a quaternary (Fuster, 1989) or heteromodal (Mesulam, 1985) level integration. That is, frontal tissue serves to integrate the products of tertiary-level integration. It may be that tertiary-level integration as carried out in the parietal cortex is more relevant to the integration and organization of experience during storage and/or retrieval than previously appreciated by those working with the source memory phenomenon. The role of the right parietal region of the cortex in the BFRT and by implication in source error may also be the result of right hemisphere and parietal involvement in attentional functions (see Posner & Peterson, 1990, for a review). As we learn more about posteriorly based integrative and attentional processes and how they relate to cognitive abilities, we may have to revise current theories espousing the unique involvement of prefrontal cortex in memory for source.

A second possibility is that the relationship between source error and the BFRT is due to a measurement confound. In our paradigm, famous and nonfamous names are presented visually so that a sensitivity in visual perception could serve subjects well in both the facial discrimination and fame judgment tasks. Subjects who do well on both would be better able to make the visual discriminations necessary on the BFRT and would be relatively more sensitive to the visual form of the nonfamous names that they had read on Phase 2 of the Famous Names Task. Individual differences in the perceived fluency that occur for information presented in the same modality could serve as a basis for accurate recognition judgements (see, for example, Johnston, Dark, & Jacoby, 1985). If this were so, the relationship between BFRT and source error would be attenuated in auditorily presented versions of the famous names task.

A third possibility is that the aspect of the BFRT that links it to our measure of source error is somewhat peripheral to the expressed goals of those who developed this measure. In the later trials of the BFRT, as discrimination between faces becomes more difficult, the correct choice requires a careful monitoring of subtle differences in contours of light and shadow. A quick, unconsidered decision is likely to be an incorrect decision. Thus, the inability to inhibit a response would impair performance on both tasks. We know that the tendency to be overly focused on current, salient events without accessing the broader conceptual context that would place the event within an appropriate perspective is an often-cited deficit associated with frontal lobe impairment (e.g., Goldman-Rakic, 1987). This inability to suppress a response that seems highly determined by one's current context can lead to problems in educational, vocational, and social settings (e.g., Binder, 1986; Lezak, 1978).

As the BFRT is self-paced and untimed, we are unable to test this hypothesis with the data gathered in our present samples. However, we have noted an interaction between speed of response and test phase for our TBI subjects and Controls in the Famous Names Task. While Controls increased decision time when faced with the possibility of source confusion during test, the TBI subjects reduced decision time. One might expect a reduction in decision time due to practice effects if there had been no change in the parameters of the task. However, the fame judgment task had become more complex during the test phase and the failure to slow down on the part of the TBI subjects could be seen as a failure to inhibit the most salient or prepotent response. That is, since the task required them to monitor fame, familiarity, for whatever cause, was quickly accepted as an indication of fame.

The same pattern of results, with respect to decision times, was documented in the performance of our older adult subjects (Dywan & Jacoby, 1990), and suggests interesting similarities in the attentional capacity of both groups. Should further investigation indicate that excessively fast responses on the BFRT are responsible for the relationship between that test and our index of source error, it would support the hypothesis put forward by Dywan and Jacoby (1990). They argued that source error represents a misattribution based on a failure to monitor source rather than the loss of a particular type of memory.

Such results would not necessarily undermine the frontal hypothesis regarding memory for source, but would help specify the nature of frontal lobe involvement. Injury to the frontal lobe can result in a variety of symptoms, depending on the severity and location of the damage (Fuster, 1989; Petrides, 1989). The inability to inhibit a prepotent response has been seen as a central feature of frontal impairment which may lead to perseverative errors, depending on the nature of the task (e.g., Diamond, 1985).

CONCLUSIONS

Our measurement of source error in this paradigm differed from that derived in the usual memory for source paradigm in that source confusion occurred in a situation where monitoring the source of item familiarity was an implicit rather than an explicit task demand. As such, our paradigm is more closely related to the real world situation, in which on-line monitoring of task- or situation-based knowledge is a requirement in many tasks as well as in social encounters. As measured in the fame judgment task, source error is manifest as an attributional error in that subjects mistake the familiarity induced by previous occurrence with the familiarity due to extraexperimental sources. While the phenomenon is usually described as a deficit in source memory, it seems to be unrelated to other indices of mnemonic function. It is, however, a far more sensitive indicator of length of coma than any of the other experimental or psychometric indices of performance that we have available in this sample of TBI subjects. As well, finding that source error could be best predicted by subjects' performance on the Benton Facial Recognition Test rather than by the WCST, the traditional index of frontal lobe functioning, has led us to hypothesize that the inability to inhibit a response may be responsible for poor performance on both tasks.

Our primary goal was to understand dissociations in function. While we can hypothesize about underlying neural substrates, these hypotheses must, of necessity, be highly tenuous given the small size of our sample, the complexity of our tasks and the inherent heterogeneity of TBI. However, irrespective of its neurophysiological correlates, the false fame effect qualifies as a clear example of memory without awareness. It demonstrates the unconscious influence of memory on a current task that is unaccompanied by awareness of that prior experience. Distinguishing the degree to which subjects are truly unaware that the prior presentation of the stimuli relates to the current task provides a serious methodological challenge (Richardson-Klavehn & Bjork, 1988). Using our paradigm, we can be certain that the false fame effect reflects an unconscious influence of memory produced by prior reading of the nonfamous names. To the extent that subjects had been aware of having read the old nonfamous names when making fame judgments, they would have been less likely, rather than more likely, to call those names famous as compared with the new nonfamous names. In our situation, conscious recollection of an earlier experience serves to oppose influences of that experience that would arise if left unopposed.

We argue that it is this reduced ability to oppose, when appropriate, the most salient aspects of ongoing experience that underlies subjects' tendency to make source errors. Moreover, the ability to inhibit an easy, but incorrect, response relies on the ability to control and focus one's attention and this attentional factor may be particularly relevant for those who have suffered head injury. Young uninjured adults can make the same source-monitoring error when they are required to make fame judgments under conditions of divided attention either at study or at test (Jacoby *et al.*, 1989c). Similarly, distraction during testing increases the chance that young, uninjured adults will repeat words that were recalled during an earlier test of free recall (Gardiner, Passmore, Herriot, & Klee, 1977). Again, this demonstrates that a reduction in attentional capacity results in an inability to monitor the appropriateness of a current response in a broader context. In this case, to avoid repetition, subjects would have to assess the appropriateness of their current recollection in the context of the items already reported.

Making the familiarity error may be a sign of disinhibition as opposed to a failure in recognition. Such distinctions are important to make because the more precisely we can understand the nature of impairment following TBI, the more appropriately we can respond to the complex array of behavioral sequelae that can occur. It is even possible that such an understanding may lead to more appropriate rehabilitative strategies and to more sensitive indices of treatment effectiveness.

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