

Direct and Indirect Memory Measures of Temporal Order and Spatial Location: Control versus Closed-Head Injury Participants

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Objective: The goal of the study was to compare control participants and participants with closed-head injury (CHI) on direct and indirect memory measures of temporal order and spatial location. **Method:** Twenty-seven CHI patients and 27 control participants were tested on "item" (i.e., words) and "contextual" (temporal order and spatial location) information. Contextual information was tested directly and indirectly by means of a format in which lists of words were presented repeatedly eight times in fixed or varying order for the temporal task and in a fixed or varying spatial position for the spatial task. The number of words recalled as well as their temporal and spatial judgment were the direct measure of item and contextual memory, respectively. The effect of the consistency of order or location was the indirect measure of contextual memory. **Results:** As expected, the CHI group was impaired on the direct measures of item memory. Also as expected, the groups did not differ in the indirect memory measures of contextual information. Contrary to predictions, however, the groups did not differ in the direct measure of contextual information. **Conclusions:** Item memory, when measured directly, is impaired in CHI patients. The finding that the groups did not differ on the direct measure of contextual information is possibly due to ceiling-level performance of the control group. Contextual information seems to be preserved in CHI patients when measured indirectly. (NNBN 1998;11:212-217)

The distinction between "item" and "contextual" information (1-3) or "source memory" (4) is widely accepted in the memory and amnesia literature. Contextual information includes different aspects of an item or event such as its temporal order, spatial location, or modality of presentation (i.e., visual vs auditory). Memory for temporal order is one of the most studied contextual information tasks and was found to be impaired in patients with frontal lobe damage even though the memory for items was intact (5-8). The findings regarding the contextual memory of amnesic patients are not conclusive. According to the contextual memory-deficit theory of amnesia, the item memory impairment observed in amnesia is the consequence of a primary context or source memory impairment (9,10).

Other researchers have found that the degree of impaired contextual memory was unrelated to the item memory impairment (11,12).

Following closed-head injury (CHI), most patients show an impaired ability to learn new verbal or visual material whether tested by recall or by recognition methods (13,14). Using the distinction presented above between item and contextual memory, these studies show that item memory is impaired in CHI patients. CHI patients have also been shown to have impaired contextual memory such as temporal order (15,16) and spatial location (16) memory. Similarly, these patients are impaired relative to controls when required to recognize the source of information in a fame judgment task (17).

Graf and Schacter (18) and Schacter (19) introduced a distinction between two types of memory processes—explicit (e.g., recall and recognition) and implicit (e.g., priming). Explicit memory requires effortful and intentional retrieval, whereas implicit memory "is revealed when

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previous experiences facilitate performance on a task that does not require conscious or intentional recollection of these experiences" (19). Most studies have found that implicit memory is preserved in amnesic patients (20). In this study, we chose to use the direct-indirect terminology (21) instead of the implicit-explicit (19) terminology in order to stress the characterization of the tasks rather than the memory systems (21,22).

In previous studies, Vakil and colleagues (15,25) have tested item memory (e.g., words and pictures) as well as contextual memory such as temporal order and modality using direct and indirect measures of memory in CHI patients. The paradigms used in these studies enabled us to examine the interaction between memory for item and memory for context. In these studies, it was consistently shown that the CHI patients were impaired when memory was assessed directly. Nevertheless, the indirect influence of contextual information on direct memory measures was proportionally similar for both the control and CHI groups (15,23-25).

The present study is another in the series of studies in which memory for temporal and spatial information is assessed directly and indirectly. Previous studies have already demonstrated that memory for temporal and spatial information is impaired following CHI (15,16). It is important to note that the paradigm used in the present study to measure temporal order indirectly is different than that used in a previous study testing temporal order (15). It is hypothesized that memory for "item" (i.e., recall of words) and memory for "context" (i.e., temporal and spatial information) are impaired in CHI patients compared with controls when assessed directly; however, the two groups are not expected to differ on the indirect measure of the contextual information.

The rationale of the paradigm employed in the present study is based on findings that the learning rate on a list of words presented repeatedly is better when the list is presented in a fixed rather than varying order (26,27). Thus, in this experiment, a list of words was presented repeatedly eight times in a fixed or varying order in the temporal task and in a fixed or varying spatial position in the spatial task. Based on these studies (26,27), it is expected that overall more words will be recalled using the fixed order rather than the varying order and location for the temporal task and spatial location task, respectively. This consistency effect of order and location is considered to be the indirect measure of contextual memory, which both groups are expected to show to the same extent.

METHODS

Participants

Two groups of subjects participated in this experiment: a control group (not brain damaged) and a CHI group. The control group consisted of 27 volunteers (14 male and 13

female) whose ages ranged from 20 to 51 years (mean = 30.89, SD = 8.55) and whose educational levels ranged from 8 to 15 years of schooling (mean = 11.89, SD = 1.55). The CHI group included 27 patients (17 male and 10 female) whose ages ranged from 20 to 51 years (mean = 30.19, SD = 8.94) and whose educational levels ranged from 8 to 15 years of schooling (mean = 11.63, SD = 1.93). The groups did not differ significantly on the variables of age ($t(52) = 0.30, p > 0.05$) or educational level ($t(52) = 0.54, p > 0.05$). Table 1 provides a more detailed description of the patient group. The CHI patients recruited for the study were from the rehabilitation program at the Loewenstein Rehabilitation Center. As can be seen in Table 1, 4 of the patients arrived conscious at the hospital. For the rest of the patients, the length of coma ranged from 1 to 23 days. The time elapsed from injury to testing ranged from 13 to 68 months.

Stimuli

Fifty-four high-frequency Hebrew words (>50 per 200,000 words) (28) were used to construct three 18-item presentation lists. Two of the lists were used for the temporal order memory task: one list was presented in a "fixed order" and the other was presented in a "varying order."

Fixed Order

Each word of the list was typed on a 6.5 × 6.5-cm card, and the list was arranged in random order. It was presented eight times using the same deck of cards in the same order.

Varying Order

To enable the presentation of the list eight times in a different order each time, the words of the list were typed eight times on cards as above. The eight sets of cards were then arranged each time in a different order, pseudorandomly, so that any sequence of three words was never repeated from trial to trial. The third list was used for the spatial location task constructing fixed and varying spatial location presentations. A large card (19.5 × 19.5 cm) was divided equally by horizontal and vertical lines, creating a matrix of nine 6.5 × 6.5-cm squares. Just one word was typed in one of the squares of the card. Each word from the list was typed eight times: half of the words were typed repeatedly eight times in the same location (i.e., the same square of the nine squares on the card) and the other half were typed in eight different locations. The four sets of the list were arranged pseudorandomly, with fixed and varying words mixed within each set as well as between sets so that any sequence of three words was never repeated from trial to trial.

Testing Procedure

Each participant was tested individually, and the order of testing was counterbalanced between temporal and spatial tasks. Furthermore, within the temporal order task, half

TABLE 1. Demographics of the head-injured patient group participants

Patient No.	Age (years)	Sex	Handedness	Education (years)	TAO (weeks)	Coma (days)
1	20	M	R	12	23	1
2	51	M	R	12	17	No
3	37	M	R	10	27	9
4	32	M	R	15	29	2
5	20	F	R	10	13	21
6	26	F	R	12	27	7
7	26	F	R	12	23	1
8	32	M	R	12	33	23
9	34	F	R	15	19	12
10	22	M	R	10	14	7
11	29	M	R	12	56	4
12	50	M	R	12	27	1
13	42	M	R	12	62	1
14	34	M	R	13	52	No
15	35	M	R	12	47	5
16	37	M	R	12	26	16
17	22	F	R	12	33	3
18	25	F	R	14	65	2
19	27	F	R	12	68	1
20	21	F	R	12	25	7
21	42	M	R	10	32	3
22	25	M	R	12	36	No
23	24	M	R	12	34	No
24	28	M	R	14	47	2
25	32	M	R	10	36	21
26	37	F	R	8	38	10
27	24	F	R	12	36	4

R, right; TAO, time after onset.

of the participants were tested in the fixed order condition first and the other half were tested in the varying order first. With the exception of a few patients, both parts of the experiment were administered to the participants on the same day with a 10-minute break between the two parts.

Temporal Task

In the fixed order condition, the list was presented repeatedly eight times in the same order using the same deck of cards each time. In the varying order condition, eight different decks of cards were used in which the list was arranged in a different order for each deck. The cards were presented one at a time for 3 seconds. In neither of the testing conditions was the participants' attention drawn to the order of presentation. Participants were told that they would be presented with a list of words a number of times and that the words would be presented on cards. They were also informed that following each trial, they would be asked to freely recall as many words as possible in any order. The number of words recalled following each of the eight trials in the fixed and varying orders (i.e., total of 16 scores) was recorded by the experimenter. The direct test of temporal order was conducted following the fixed order task; participants were presented with the words from the list written in an order different from that in which they had been presented originally. Participants were then asked to rewrite the words in their original order.

Spatial Task

This procedure was identical to the previously mentioned task but differed in that just one list was presented eight times. Half of the words in the list were presented each time in the same spatial location on the card and half were presented in a different location at each trial. Similar to the temporal order task, the participants' attention was not drawn to the location of the words. Following each trial, participants were asked to recall as many words as possible. For the direct test of spatial location, participants were presented with the nine words presented in a fixed location, with each word written on a 6.5 × 6.5-cm card. The participants were asked to judge the location in which the words had appeared by pointing at a square on an empty matrix of nine squares. The empty matrix was the same size of the original matrix in which the words were originally presented. The number of correct spatial location judgments was recorded by the experimenter.

RESULTS

Temporal Order

Table 2 presents the mean number (and SD) of words recalled in the eight learning trials of fixed and varying order by the control and CHI groups. The results were submitted to a mixed-design ANOVA in order to analyze

TABLE 2. Number of words recalled in the eight learning trials of fixed and varying order by the control and CHI groups*

	CHI (n = 27)	Control (n = 27)
Fixed order		
Trial		
1	6.704 (2.493)	9.296 (2.350)
2	9.259 (3.096)	11.963 (2.504)
3	11.185 (2.802)	13.926 (2.319)
4	12.296 (2.658)	14.889 (2.547)
5	13.296 (2.317)	15.704 (2.233)
6	13.889 (2.562)	16.259 (1.953)
7	14.185 (2.219)	16.667 (1.664)
8	14.704 (2.163)	17.037 (1.126)
Varying order		
Trial		
1	6.037 (1.931)	8.852 (2.179)
2	7.556 (1.968)	11.148 (2.612)
3	8.667 (2.449)	12.296 (2.826)
4	9.815 (2.704)	12.852 (2.088)
5	10.111 (2.207)	13.963 (2.157)
6	10.630 (2.204)	15.296 (1.996)
7	11.111 (2.118)	14.704 (2.415)
8	10.741 (2.505)	15.148 (2.413)

* Values are mean (standard deviation).

the effect of group (CHI and control) by order of presentation (fixed vs varying) and by number of trials (1–8 trials). All three main effects reached significance. Overall, the control group recalled more words than the CHI group ($F(1, 52) = 39.60, p < 0.001$). More words were recalled in the fixed order of presentation than in the varying order of presentation ($F(1, 52) = 103.31, p < 0.001$). The main effect for trial also reached significance, reflecting the overall increase in number of words recalled from trial to trial ($F(7, 364) = 288.77, p < 0.001$). As can be seen in Table 2, the CHI group benefited overall even more than the control group from the consistency of presentation, which is reflected in the group \times order interaction ($F(1, 52) = 8.68, p < 0.005$). This differential benefit is expressed not just overall but also as a function of trials as expressed in the triple interaction of group \times order \times trial ($F(7, 364) = 2.24, p < 0.03$). The CHI advantage is probably due to a ceiling level effect in the control group's performance. This point is discussed further later in this article.

In the analysis of the direct measure of temporal order judgment, a Pearson product-moment correlation was calculated for each participant, with a comparison between the order judged and the order in which the words were originally presented (29). This correlation score reflects the accuracy of temporal order judgment. The groups did not significantly differ from each other in their temporal order judgment ($r(52) = 0.33, p > 0.05$ [means are 0.792 and 0.806 for the control and CHI groups, respectively]).

TABLE 3. Number of words recalled in the eight learning trials of fixed and varying spatial location by the control and CHI groups*

	CHI (n = 27)	Control (n = 27)
Fixed location		
Trial		
1	3.296 (1.353)	4.667 (1.687)
2	4.593 (1.338)	6.556 (1.476)
3	5.148 (1.586)	6.667 (1.414)
4	5.741 (1.483)	7.370 (1.363)
5	6.296 (1.171)	7.481 (1.221)
6	6.556 (1.219)	8.222 (1.013)
7	6.630 (1.391)	8.222 (1.013)
8	7.000 (1.387)	8.407 (0.797)
Varying location		
Trial		
1	2.778 (1.553)	3.593 (1.886)
2	3.037 (1.454)	4.481 (1.868)
3	3.741 (1.228)	5.370 (2.097)
4	4.148 (1.512)	5.741 (1.509)
5	4.259 (1.375)	6.037 (1.675)
6	4.481 (1.424)	6.296 (1.683)
7	4.704 (1.171)	6.185 (1.733)
8	4.444 (1.251)	6.296 (1.728)

* Values are mean (standard deviation).

Spatial Order

Table 3 presents the mean number (and SD) of words recalled in the eight learning trials of fixed and varying spatial location by the control and CHI groups. The results were submitted to a mixed-design ANOVA in order to analyze the effect of group (CHI and controls) by location (fixed vs varying) and by number of trials (1–8 trials). As in the temporal order analysis, all the main effects reached significance. The control group recalled more words overall than the CHI group ($F(1, 52) = 29.74, p < 0.001$). More words were recalled overall in the fixed location of presentation than in the varying location ($F(1, 52) = 195.33, p < 0.001$). The main effect for trial also reached significance due to the overall increase in the number of words recalled from trial to trial ($F(7, 364) = 141.89, p < 0.001$). The only interaction that reached significance was the location \times trial ($F(7, 364) = 5.13, p < 0.001$). As can be seen in Table 3, this interaction reflects the steeper learning rate under the fixed location of presentation as compared with the varying location of presentation. When the direct measure of spatial location judgment was analyzed, the groups did not differ significantly ($t(52) = 1.56, p > 0.05$). The control group made an average of 5.81 accurate spatial location judgments and the CHI group made an average of 5.26 accurate spatial location judgments.

The length of coma has been reported as one of the better measures of severity of head injury with regard to the prediction of outcome. Gilchrist and Wilkinson (30) found that the length of coma was closely related to the degree of recovery from the injury in a group of young CHI

patients. Hall et al (31) reported that the length of coma was one of the severity measures that highly correlated with disability scales. Judging by the length of coma (see Table 1), the CHI group in the present study is not homogeneous with regard to the severity of injury. Therefore, additional analyses were conducted in order to analyze the effect of severity on performance. The effect of severity was analyzed based on four different scores: total number of words recalled in the temporal task, total number of words recalled in the spatial task, the correlation score as the index of temporal judgment, and number of correct spatial location judgments. Of these scores, just the spatial judgment score correlated significantly with the length of coma ($r(27) = -0.413, p < 0.04$). In addition, the CHI group was divided into two subgroups of less ($n = 14$) or more ($n = 13$) than 3 days of coma, which is the median length of coma for this sample. These two subgroups differed on the spatial but not on the temporal measures. The less severe group scored better than the more severe group on the number of correct spatial location judgments ($t(25) = 2.72, p < 0.02$ [means are 5.93 and 4.54 for the less and more severely injured groups, respectively]). These two groups significantly differed in the total number of words recalled in the spatial location task ($t(25) = 2.09, p < 0.05$ [means are 82.50 and 70.77 for the less and more severely injured groups, respectively]).

DISCUSSION

In the present study, control and CHI participants were tested directly on memory for item (i.e., words) and for context (i.e., temporal order and spatial location). The effect of consistency of order and location was considered to be an indirect measure of memory for temporal and spatial information. In accordance with previous reports in the literature (13,14), survivors of head injury exhibited impaired item memory when measured directly. In both tasks (temporal and spatial), the control group recalled significantly more words than the CHI group.

As is the case for amnesics, previous studies have indicated that the memory of CHI patients is preserved when measured indirectly (23,32). Furthermore, contextual memory is also preserved in CHI patients when measured indirectly (15,23–25). The theoretic contribution of these studies is that just like the findings with item memory, contextual memory is also preserved when measured indirectly. Our results are consistent with these reports. The significant group \times order and group \times order \times learning trial interactions in the temporal order task are due to the steeper learning rate of the CHI group as compared with that of the control group. As can be seen in Table 2, the control group recalled 16.26 words of the 18-word list by the sixth trial, indicating a ceiling level effect for this group. Therefore, it is safe to conclude that the CHI group benefited to

at least the same extent as the control group from the consistency of temporal order. The nonsignificant group \times order and group \times order \times learning trial interactions in the spatial location task indicate that both groups benefited to the same extent from the consistency in the spatial location presentation. In other words, as predicted, the CHI group did not benefit, in relation to the initial baseline, less than the control group from temporal and spatial contextual cues.

With regard to the effect of severity of injury on the temporal and spatial tasks, it is unclear to us why such an effect was found just on the spatial tasks. Based on the literature associating temporal judgment with the functioning of the frontal lobes (5–8), temporal judgment would be more highly expected to be sensitive to severity of injury than spatial judgment.

Previous studies (15–17) have also consistently reported impaired contextual memory in CHI patients when measured directly. In the present study, however, the groups were not significantly different from each other when temporal and spatial information was measured directly. In a previous study conducted in our laboratory using similar groups along with the same list of words repeated in a fixed order, the CHI and control groups differed significantly when temporal order was measured directly (15). The crucial difference between the previous experiment and the present one is in the number of repetition trials (i.e., 5 vs 8 trials, respectively). In the previous experiment, the temporal order scores following five learning trials were 0.780 and 0.480 for the control group and the CHI group, respectively. In this study, following eight learning trials, the temporal order scores were 0.792 and 0.806 for the control and CHI groups, respectively. A comparison of these two sets of results from the two experiments indicates that although the control group reached its peak performance by the fifth trial, the CHI group continued to benefit from following trials. Evidently, the lack of difference in the temporal order judgment in this study is due to a ceiling level performance of the control group. It is reasonable to assume that similar to temporal order, the lack of difference in spatial location judgment is also due to a ceiling level performance of the control group. The fact that the CHI performance is better following eight learning trials rather than five learning trials is important in itself and has some implications for rehabilitation. This finding is a clear indication of the learning ability of CHI patients for contextual information even under incidental learning conditions.

In conclusion, the findings of the present study are consistent with those of previous studies (13,14), demonstrating that memory for "item" when measured directly is impaired in CHI patients. Contrary to previous findings (15–17), CHI patients participating in this study have shown preserved contextual memory even when measured directly. These results are most probably due to the exten-

sive amount of learning (i.e., 8 trials) compared with that of previous studies, which enabled the CHI patients to continue to improve, although the control group reached a ceiling level at an earlier stage of learning. Finally, as expected, contextual memory was preserved in CHI patients when measured indirectly. These results are consistent with previous findings in CHI (15,23-25) and amnesic patients (20).

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