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Declarative and Nondeclarative Sequence Learning Tasks: Closed-Head Injured Patients Versus Control Participants*

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ABSTRACT

Patients who sustained closed-head injury (CHI) have been shown to have impaired memory for temporal order when measured under intentional, but not incidental, retrieval conditions. A group of 26 patients who sustained CHI and a matched control group of 26 individuals were tested on a declarative sequence learning task – "Chain Making" (CM), and a nondeclarative sequence learning task – Tower of Hanoi puzzle (TOHP). The TOHP is a problem solving task that requires planning and a strategic approach. The latter are cognitive processes known to be impaired following frontal lobe damage, as has been frequently documented in CHI patients. The goal of the present study was to test whether CHI patients' nondeclarative learning as measured by the TOHP task is preserved, as seen in amnesic patients, or impaired, as would be predicted following frontal lobe damage. Half of the participants in each group underwent active training, and the other half went through passive training of the tasks. The results demonstrate that the control group outperformed the CHI group (in most measures) in both declarative and nondeclarative sequence learning tasks. The effect of type of training differed for the two tasks: while performance of the control group on the TOHP was better under passive training (CHI patients did not improve on either one of the training modes), performance on the CM task was better under active training for both groups. The results are discussed in light of the role of the frontal lobes in memory generally, and in sequence learning particularly.

The dissociation between impaired and preserved memory task performance has been proposed to reflect different memory systems – declarative (or explicit) versus nondeclarative (or implicit) (Squire, 1994). Priming and skill learning are the major two subtypes of nondeclarative memory (Moscovitch, Goshen-Gottstein, & Vierzen, 1994; Squire & Zola-Morgan, 1991). According to Moscovitch et al. "procedural tests are not concerned with acquisition of a particular item but rather with learning a general cognitive or sensorimotor skill... memory is inferred from changes in performance with practice" (p. 621). The Tower of Hanoi puzzle (TOHP) is one such task, in which amnesics have demonstrated the same learning rate as normal control participants (Cohen & Corkin, 1981; Cohen, Eichenbaum, Deacedo, & Corkin, 1985).

Declarative memory has been shown to be impaired for patients with closed-head injury (CHI), whether tested by recall or recognition (for review, see Baddeley, Sunderland, Watts, & Wilson, 1987; Levin, 1989). In recent years nondeclarative memory has been studied in CHI patients, primarily with priming tasks (e.g., word stem completion), in which they show normal performance (Mutter, Howard, Howard et al., 1990; Vakil, Biederman, Liran et al., 1994). In a more recent study, CHI patients' performance was normal when tested for perceptual, but not conceptual, priming (Vakil & Sigal, 1997). The authors attribute the impaired conceptual priming

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to frontal lobe damage, which has frequently been documented as a consequence of closed-head injuries (Adams 1975; Levin, Benton, & Grossman, 1982). TOHP is classified by Moscovitch et al. (1994) as a rule-based procedural task, which requires the acquisition or application of sequential patterns or rules. This task involves strategic processes such as monitoring, planning, and developing and testing hypotheses. The TOHP is also known to be sensitive to the functioning of the frontal lobes (Lezak, 1983). Accordingly, it is predicted that sequence learning as tested by TOHP, although preserved in amnesic patients, will be impaired in CHI patients due to frontal lobe damage.

The fundamental difference between the declarative and nondeclarative tasks is that the latter are independent of conscious recollection of the information learned (Willingham, Nissen, & Bullemer, 1989). However, in most studies the declarative and nondeclarative tasks differ in other aspects as well, which makes comparison between the two tasks problematic. More specifically, when compared to the learning of declarative information, most skill learning tasks require more active involvement in the learning process. For example, solving the TOHP requires planning and execution of every single move. By contrast, in a typical declarative task the subject is only required to listen to a list, and is then asked to recall as many words as possible. Furthermore, the TOHP could be viewed as a sequencing learning task, i.e., by consequence of their training, subjects learn the sequence of moves that leads to solution in a minimum number of steps. In list recall, however, the sequence of words is usually irrelevant, and the number of items (e.g., words) recalled is the critical measure of memory.

The goal of the present study is threefold: first, to test whether CHI patients' skill learning, when measured by the TOHP task, is preserved as in amnesic patients, or impaired, as would be predicted following frontal lobe damage. Second, to determine whether active and passive learning will have a differential effect on the declarative and nondeclarative tasks. Third, to examine whether active learning of the TOHP will lead to improved transference of the skill learned to a more difficult task. As in the case of the nondeclarative task (i.e., TOHP), when choosing the declarative task, we ensured that it would require 15 steps of sequence learning. This point will be further clarified in the method section. The fact that the declarative and nondeclarative tasks require sequence learning has methodological as well as theoretical importance. In previous studies CHI patients have been shown to have impaired memory for temporal order when measured under an intentional retrieval condition (Vakil & Tweedy, 1994), but not under an incidental retrieval condition (Vakil, Blachstein, & Hoofien, 1991). According to these findings it would be predicted that the declarative, but not the nondeclarative, sequence learning task will be impaired in CHI patients.

METHOD

Participants

Two groups participated in the present study: a control group (non-brain damaged) and a CHI group. The control group consisted of 26 volunteers (15 males and 11 females) ranging in age from 20 to 59 years ($M = 26.31$). Their education ranged from 12 to 17 years ($M = 13.27$) of schooling. The CHI patients were recruited for the study from a population of patients admitted to the Loewenstein Hospital (Israel) for rehabilitation following head injury. This group was composed of 26 patients (17 male and 9 female) ranging in age from 17 to 57 years ($M = 27.32$). Their education ranged from 10 to 15 years ($M = 12.25$) of schooling. The groups did not differ significantly in their age, $t(50) = .34$, $p > .05$, but the control group had significantly more years of schooling than the CHI group, $t(50) = 2.71$, $p < .01$. Table 1 provides a more detailed description of the patient group including the length of coma, the Glasgow Coma Scale, and time after onset. An interdisciplinary team of department heads evaluated patients referred to the study at least one month prior, as being beyond Post Traumatic Amnesia. Thus, patients' intellectual and linguistic functioning was at a level enabling adequate responsiveness to the task requirements based on the tests conducted. Participants in both groups were proficient in Hebrew, and had no history of mental illness, alcoholism or drug abuse.

Tests and Procedure

Participants were administered two sequence tasks, one declarative, the "Chain Making" (CM) task, and

Table 1. Demographics of the CHI Patient Group.

Patient	Age	Sex	Edu	TAO	Coma	GCS
1	17	F	11	9	5	8
2	25	M	12	14	10	
3	35	M	12	16	10	5
4	21	M	12	52		7
5	35	M	11	3		11
6	27	M	14	16	14	5
7	20	M	12	67	80	5
8	23	M	12	24	14	
9	18	M	12	20	7	4
10	26	F	12	12	2	11
11	26	F	13	8	10	
12	21	M	12	5	2	
13	20	F	12	26	4	4
14	20	F	10	4	8	6
15	19	M	12	12	14	7
16	36	F	12	12	14	3
17	24	F	12	4	4	
18	57	M	15	18		5
19	20	M	12	12	14	8
20	34	M	12	8	7	7
21	23	F	15	18	22	3
22	21	M	12	56	2	7
23	32	M	12	36	30	4
24	33	M	10	30	14	4
25	43	F	10	3	18	3
26	29	M	15	72	120	7

Edu = education (years); *TAO* = time after onset (months); *Coma* = length of coma (days); GCS = Glasgow Coma Scale.

the other nondeclarative, the TOHP (Cohen & Corkin, 1981; Cohen et al., 1985). Participants were tested individually, in two sessions, one week apart. The TOHP was administered in the first session and the CM task in the second session. In order not to affect the implicit nature of the nondeclarative task, the declarative task was always presented last. Each task was learned in either an active or passive mode. Participants from each group were randomly assigned to one of the four training combinations: both tasks active, both passive, declarative active and nondeclarative passive, declarative passive and nondeclarative active. Thus, each task was learned by half of the members of each group in the active mode and by the other half in the passive mode. The subgroups did not differ significantly from each other in age and education or (for the CHI subgroups) on the duration of coma, time after onset or the Glasgow Coma Scale.

Tower of Hanoi Puzzle

A computerized (for PC) version of the task was administered. Three pegs, numbered 1 to 3, are presented on the screen. At the outset, four disks are arranged on the leftmost peg, with the largest disk at the bottom and the smallest disk on the top. Participants were told that the goal is to move the four disks in the minimum number of steps from the leftmost peg (#1) to the rightmost peg (#3). They were also told that they can move only one disk at a time, they cannot place a larger disk on a smaller disk, and that they can use the middle peg as well. In order to move disks, participants must press 1, 2, or 3 on the keyboard, first selecting the peg number from which to move the disk, and then the peg number to which to move the disk. The computer automatically registers the number of moves and the time required for solving the task. The minimum number of moves necessary to successfully complete the four-disk problem is 15, whereas 5 disks necessitate a minimum of 31 moves. The TOHP, with four disks, was carried out in four stages, as follows:

Stage 1: Baseline measure

Participants were asked to solve the TOHP (with 4 disks) in as few moves as they could. At this stage the individual baseline level was established. The number of moves and time required for each participant to successfully complete the problem were recorded. These measures served as a baseline for both age groups in the two training conditions. Performance after the different training conditions was compared to baseline values.

Stage 2: Training

In this stage, the participants from the "active" group were asked to solve the TOHP again (with 4 disks) in as few moves as they could. The "passive" group was also presented with the TOHP (also with 4 disks), but asked to solve it by following the experimenter's verbal instructions. The sequence dictated to the "passive" group was the optimal solution (i.e., 15 moves). The procedure for both the "active" and the "passive" groups was repeated three times consecutively.

Stage 3: Test

In order to measure the immediate effect of the two training methods, all participants were once again asked to solve the TOHP (with 4 disks) in an "active" manner (i.e. without any intervention by the experimenter).

Stage 4: Transfer

In order to assess ability to transfer the learned skill to a more difficult task, all participants were asked to solve a more difficult level of the TOHP in the "active" manner, with five disks requiring a minimum of 31 moves to complete.

Chain Making
This task utilizes 15 strips of cloth, each of which is a different color. The strips form links that can be attached to each other to form a chain. In the learning stage participants from the "active" group were asked to prepare a chain from the 15 strips in any order that they like. They were also told that they would be asked at a later stage to reconstruct the chain from memory, in the same order. The examiner recorded the exact sequence of color in which each participant in this group had arranged the chain. The "passive" group was asked to prepare the chain in the sequence of colors determined by the examiner. The testing stage for the active and passive groups was identical. Two minutes after completing the chain, participants were given the strips and were asked to prepare the chain in the same order as in the learning stage. The sequence of strips in the chain was recorded by the examiner.

RESULTS

Because of the significant difference in education between the groups, in all the statistical analyses education was used as a covariance.

Tower of Hanoi Puzzle
Two separate dependent measures were employed to analyze the data: number of moves for solution and puzzle solution time. Tables 2 and 3 present the mean number of moves and the time (in sec.), respectively, required by the control and CHI groups to solve the TOHP pre- and post training under active and passive learning conditions. For each one of the dependent variables (i.e., moves & time) a mixed design ANOVA was conducted to analyze the effects of group (control & CHI), training mode (passive vs. active), learning (pre training vs. post training) and education as a co-variance. The former two are between-subject factors and the latter one is a within-subject factor.

Number of Moves
As can be seen in Table 2, the control group needed fewer moves to solve the TOHP, $F(1, 48) = 4.10$, $p < .05$, and participants who underwent passive training needed fewer moves to solve the TOHP, as compared with participants who went through the active training mode, $F(1, 48) = 5.10$, $p < .05$. The overall learning effect was also significant, $F(1, 48) = 4.29$, $p < .05$, but this main effect should be interpreted cautiously because of the significant Group by Learning interaction, $F(1, 48) = 5.33$, $p < .01$. The inter-

Table 2. Mean and (Standard Deviations) of Number of Moves Required by the Control and CHI Groups to Solve the TOHP Pre and Post Training Under Active and Passive Learning Conditions.

	Control				CHI			
	Active		Passive		Active		Passive	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Pre Training	24.00	(7.70)	23.62	(7.02)	27.31	(7.27)	22.23	(7.88)
Post Training	20.23	(8.22)	16.23	(1.74)	29.31	(15.05)	21.08	(7.01)

Table 3. Mean and (Standard Deviations) of Time (in sec.) Required by the Control and CHI Groups to Solve the TOHP Pre and Post Training Under Active and Passive Learning Conditions.

	Control				CHI			
	Active		Passive		Active		Passive	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Pre Training	239.85	(136.84)	306.34	(183.31)	454.31	(168.22)	358.36	(153.78)
Post Training	104.39	(82.37)	129.85	(91.81)	210.00	(100.53)	193.92	(179.58)

action indicates that the groups differ in their learning rate. While the control group required 23.81 and 18.23 moves pre- and post training, respectively (saving of 17.57%), the CHI group did not actually benefit at all from the training (24.77 and 25.19, pre- and post training, respectively). Simpler analyses were conducted in order to test more specifically the training mode effect for each group separately. Pre training (baseline) performance of the control and CHI groups under the two training conditions did not differ significantly. In post training, both groups showed a trend toward superior performance under passive versus active training, $t(24) = 1.72$, $p < .10$, and $t(24) = 1.79$, $p < .10$, for the control and CHI groups respectively. Post training, the control group required significantly fewer moves than the CHI group to solve the TOHP under passive training, $t(24) = 2.42, p < .05$, and a similar trend under active training, $t(24) = 1.91$, $p < .07$. The control group under passive training was the only subgroup that showed significant change from pre- to post training, $t(12) = 3.83$, $p < .005$.

Solving Time

The same analysis as above was conducted with solving time as the dependent measure. The only main effects that reached significance were group, $F(1, 47) = 9.86, p < .005$, and learning, $F(1, 47) = 7.39$, $p < .01$. These results indicate that the control group needed less time than the CHI group to solve the TOHP, and less time was required to solve the TOHP post training as compared to pre training (see Table 3).

Transfer Task – TOHP with 5 Disks

This task was given in order to assess ability to transfer the learned task (with 4 disks) to a more difficult task (with 5 disks). Table 4 presents the mean number of moves and time (in sec.) required by the control and CHI groups to solve the TOHP with five disks under active and passive learning conditions. The effects of group (control & CHI) and training mode (passive vs. active) were analyzed for the number of moves for solution and solution time of the TOHP. None of the main effects or the interactions reached significance.

In order to analyze more directly the transfer effect, the control and the CHI groups were compared on a difference score (post training minus transfer trial). The control group was found to have a significantly larger difference score ($M = 43.00$, $SD = 23.15$) than the CHI group ($M = 29.77, SD = 20.37$), $t(50) = 2.19, p < .05$. These results demonstrate a significant *negative* transfer effect for the control group compared to the CHI group.

Chain Making

For analysis of the memory of sequence of strips in the chain, a Pearson product-moment correlation was calculated for each participant, comparing the sequence of the strips at the learning stage and the testing stage. This correlation score reflects the accuracy of memory for sequence (Tzeng, Lee, & Wetzel, 1979). Table 5 presents the correlation scores of the control and CHI groups under active and passive conditions. A two-way ANOVA was conducted to analyze the effects of group (control & CHI) and training mode (passive vs. active) on the declarative sequence task. As can be seen in Table 5, the control group was more accurate than the CHI group in reproduction of the sequence, $F(1, 47) = 4.52$, $p < .05$, and performance under the active mode was more accurate than under the passive

Table 4. Mean and (Standard Deviations) of Number of Moves and Time (in sec.) Required by the Control and CHI Groups to Solve the TOHP With Five Disks Under Active and Passive Learning Conditions.

	Control				CHI			
	Active		Passive		Active		Passive	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Move	61.00	(21.16)	61.46	(27.85)	57.62	(16.73)	52.31	(15.98)
Time	318.08	(258.89)	309.15	(228.80)	405.69	(286.39)	310.08	(255.74)

Table 5. Mean and (Standard Deviations) of the Correlation Scores (as the Accuracy Measure) of the CM Task Under Active and Passive Learning Condition for the Control and CHI Groups.

	Control		CHI	
	M	(*SD*)	*M*	(*SD*)
Active	.761	(.314)	.529	(.326)
Passive	.529	(.363)	.385	(.223)

mode, $F(1,47) = 4.52$, $p < .05$. The nonsignificant interaction indicates that both groups benefited to the same extent from active, as compared to passive, learning.

In order to assess the effect of the severity of injury, Pearson product-moment correlations were calculated for the CHI group between the length of coma, Glasgow Coma Scale, and time after onset, with the different memory measures previously analyzed. Length of coma correlated significantly with the number of moves needed to solve the TOHP pre training, $r(23) = .43$, $p < .05$, and post training, $r(23) = .57$, $p < .005$. The other severity measures were not significantly correlated with the memory measures.

DISCUSSION

As predicted, the CHI group was impaired in declarative sequence learning (i.e., CM task). Previous studies in the literature have reported impaired sequence learning of verbal material in CHI patients (Vakil et al., 1991; Vakil & Tweedy, 1994). The present study extends these findings by demonstrating CHI patients are impaired in sequence learning on a nonverbal task as well. Furthermore, both groups performed better to the same extent under active rather than passive learning. This finding is consistent with previous reports in the literature in which active learning of temporal order compensated for deficient performance in frontal lobe patients (McAndrews & Milner, 1991). The findings that CHI patients benefit here from active training, whereas they do not benefit from deep encoding (Vakil & Sigal, 1997), suggest that the underlying mechanism of these two types of manipulations is different. CHI patients do not benefit from deep encoding that is dependent on conceptual processing, possibly due to their impaired frontal lobes (Adams 1975; Levin et al., 1982). The observed change following active training could be attributed to additional motor encoding, or because it helps to focus attention on the task at hand. More research is needed in order to determine the exact nature of the underlying mechanism in active training as compared to deep encoding.

With regard to the TOHP, it is important to note that we found wide variability in task performance within each group. This finding raises serious doubts about the usefulness of this task as a diagnostic tool. The control and CHI groups did not significantly differ in the number of moves required to solve the 4-disk or 5-disk TOHP. However, overall the control group performed the 4-disk task faster than the CHI group, and the learning rate of the control group, as measured by number of moves, was steeper than that of the CHI group. As a consequence, post training, the controls' performance was better than that of the CHI group. Thus, whereas classic amnesic patients demonstrate preserved ability to learn the TOHP (Cohen & Corkin, 1981; Cohen et al., 1985), CHI patients, consistent with reports of frontal lobe patients (see Lezak, 1989), are impaired in at least some aspect of this task (i.e., solving time & learning rate). This difference between the two patient groups could be attributed to the different brain regions involved in the pathology of each group. In amnesic patients the middle temporal and diencephalon areas are primarily involved (Squire & Zola-Morgan, 1991), while the frontal lobes are usually associated (but definitely not exclusively involved) with closed head injuries (Adams 1975; Levin et al., 1982). Furthermore, the absence of brain imaging results is a limitation of this study. While test findings (for at least some, but not necessarily all) CHI patients may be consistent with frontal lobe involvement, such involvement remains speculative.

In previous studies we have stressed the importance of the dissociation between baseline and learning rate performance in skill learning in general, and in the TOHP in particular. It was found that aging (Vakil & Agmon Ashkenazi, 1997) and mental retardation (Vakil, Shelef-Reshef, & Levi-Shiff, 1997) affected baseline performance, but not the learning rate of the TOHP. In this study we demonstrate that in addition to the fact that the CHI group perform the task more slowly at baseline, their learning rate is impaired as compared to controls when measured by the number of moves required to solve the task. Further studies are required (e.g., with pure frontal lobe patients or with imaging studies) in order to determine more specifically the contribution of the frontal lobes and other brain regions to the different components of the TOHP (i.e., baseline and learning rate).

CHI patients have been shown to have impaired memory for temporal order when measured under intentional retrieval condition (Vakil & Tweedy, 1994), but not under incidental retrieval condition (Vakil et al., 1991). Based on these findings it was predicted that the declarative, but not the nondeclarative, sequence learning task would be impaired in CHI patients. However, the CHI patients were impaired in both declarative and nondeclarative learning tasks. A possible explanation is that although the TOHP is a nondeclarative memory task, it is a problem solving task that requires planning and a strategic approach, which are among the cognitive processes known to be impaired in frontal lobe patients (Lezak, 1989).

Unlike the finding with declarative sequence learning, passive training led to better performance than active training in the skill learning task – only for the control group. However, the CHI group did not show a learning effect under either active or passive training conditions. In a previous study with a similar paradigm (Vakil, Hoffman, & Myzliek, 1997) the older adult group showed that passive training was beneficial on the immediate test but not on the one week delayed test. The younger group did not show a differential effect for the two types of training on either immediate or delayed tests, and both age groups benefited more from active than passive training when asked to solve a more difficult (transfer) task (i.e., 5 disks). In the present study we used immediate and transfer tests, but not a one-week delayed test. In both studies passive training was more beneficial than active training when tested immediately (although in the previous study only the older group showed the effect). However, contrary to our prediction and to the previous findings, the type of training did not have an effect on the transfer task. Furthermore, the results demonstrate a significant *negative* transfer effect (post training minus transfer) for the control group compared to the CHI group. The discrepancy in results may be due to the fact that the age range of the matched control group in the present study is much larger (20 to 59 years, $M = 26.31$) than that of the younger group in the previous study (18 to 20 years, $M = 21.92$) (Vakil et al., 1998), which lead to great variability in performance. As can be seen in Table 4, the standard deviation was even larger for the control groups (21.16 and 27.85 for active and passive training, respectively) than for the CHI group (16.73 and 15.98 for active and passive training, respectively).

Finally, length of coma has been reported to be one of the better measures of severity of head injury with regard to prediction of outcome. Gilchrist and Wilkinson (1979) found in a group of young CHI patients that the length of coma was closely related to the degree of recovery from the injury. Hall, Hamilton, Gordon, and Zasler (1993) found that the length of coma was one of the severity measures highly correlated with disability scales. In our results as well, the length of coma was the most sensitive measure of severity of injury, based on the fact that it was the only measure correlated with some of the memory scores. Although CHI patients were impaired as compared to the control group on several measures of declarative and nondeclarative sequence learning tasks, performance on the TOHP was the measure most related to severity of injury as measured by the length of coma.

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