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Script knowledge after severe traumatic brain injury

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Abstract

Severe diffuse traumatic brain injury (TBI) may impair the performance of daily-life complex activities. The aim of the present study was to assess whether these difficulties are related to a representational impairment of action knowledge. Two tasks requiring the manipulation of scripts were used. The first (*script reconstitution*) required subjects to sort cards describing actions belonging to 4 different scripts, presented in a random order. The second (*script generation*) required subjects to generate actions belonging to a given script. The results showed that TBI patients had preserved access to goal representation and action knowledge. However, they demonstrated (1) significant impairments when they had to deal with simultaneous competing sources of information and (2) a lack of inhibitory control on routine overlearned skills. Patients' performance was significantly correlated with behavioral modifications in everyday life. These data suggest that action impairment in severe TBI patients cannot be attributed to an impairment of action knowledge *per se*. As previously suggested by Schwartz et al., a restriction of limited-capacity processing resources may account for the observed deficits. (*JINS*, 2001, 7, 795–804.)

Keywords: Script, Executive functions, Traumatic brain injury

INTRODUCTION

Severe traumatic brain injury (TBI) may give rise to disturbances in the performance of daily-living activities that look clinically similar to the kind of disruptions reported after focal lesions of the prefrontal cortex (Levin et al., 1991; Mattson & Levin, 1990). Such disturbances include deficient planning, difficulty in adapting to novel, nonroutine conditions, problems in dealing with different simultaneous tasks, impaired judgment, poor initiation, failures of attention, and lack of behavioral control. These deficits are usually thought to be secondary to prefrontal dysfunction, either due to focal prefrontal lesions (such as contusions or hematomas) or to diffuse white matter injury, which may disrupt frontal connections with other cortical and subcortical structures (Anderson et al., 1995; Gale et al., 1995). Diffuse axonal injury may produce deficits close to those observed after focal lesions of the frontal lobes (Stuss & Gow, 1992; Vilkki, 1992). Accordingly, neuropsychological deficits of

severely brain-injured patients without any focal structural lesion of the brain have been found significantly correlated with prefrontal and cingulate hypometabolism as studied by Positron Emission Tomography (Fontaine et al., 1999).

The relationships between frontal lobe dysfunction and the cognitive and behavioral disorders of TBI patients remain poorly understood. Indeed, severe TBI patients have been found impaired in the execution of simple elementary daily-life activities (Schwartz et al., 1998), hypothesized as being independent from high-level executive control of the frontal lobes (Shallice, 1988). Brain injured patients also suffer from a nonspecific slowing of information processing that has been documented extensively in a range of studies (Van Zomeran & Brouwer, 1994). Whether impaired performance in complex tasks is due to a deficient activation of low-level routine skills, related for example to slowing of information processing, or to a specific disorder in higher-level cognitive abilities is still controversial (Azouvi et al., 1996; Schwartz et al., 1998; Veltman et al., 1996).

Planning a sequence of actions is considered frequently as one of the main functions of the frontal lobes (Shallice, 1988). Studies on planning abilities of TBI survivors have

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given conflicting results. Several studies have used the Tower of London task (Shallice, 1982) and found that TBI subjects performed slower but just as accurately as controls (Cockburn, 1995; Ponsford & Kinsella, 1992; Veltman et al., 1996). In contrast, Levine et al. (1998) recently found that a group of patients with diffuse TBI used an inefficient strategy in an open-ended, nonstructured task, adapted from the Six-Element Test (Shallice & Burgess, 1991).

Cognitive theories have postulated that planning depends on the activation of representation units called scripts (Schank, 1982). Scripts are thought of as knowledge structures used for the representation of experienced events. They contain information about the temporal ordering, duration, and relative importance of events. Their structure is supposed to be similar to lexical or semantic knowledge representations, in which individual items are linked by associative rules to form a network (Bower et al., 1979; Grafman, 1994). Several studies have looked at script processing in brain-damaged patients. Patients with lesions of the prefrontal cortex are impaired in processing some aspects of script knowledge, particularly the temporal ordering of actions (Allain et al., 1999; Godbout & Doyon, 1995; Sirigu et al., 1995, 1996) or the ability to discard irrelevant actions which do not fit within the script internal structure (Allain et al., 1999; Sirigu et al., 1996).

The present study addresses the problem of planning skills in a severe TBI group by means of a script generation and reconstitution task (Sirigu et al., 1995, 1996). The tasks were chosen for two reasons: first, they have a satisfying ecological validity (manipulating actions corresponding to possible real-life events); secondly, and more importantly, they are specifically sensitive to focal frontal dysfunction (Sirigu et al., 1995, 1996). We used a paradigm proposed by Sirigu and colleagues, who recently compared the performance of patients with focal prefrontal lesions with that of patients with focal posterior damage, and normal healthy controls. In a first study, subjects were asked to generate from memory actions belonging to a given script (Sirigu et al., 1995). Focal frontal patients were able to generate a number of actions similar to controls and with the same speed. In contrast, they made more temporal sequencing errors and script rule violations (such as stopping the sequence before or after the stated end-point). When asked to make a judgment of importance on each individual action they generated, patients with frontal lesion underestimated the importance of some actions evaluated as central by controls, and overestimated other actions rated as irrelevant to achieve the goal. In a second study, frontal patients were required to sort cards describing actions belonging to four different scripts, presented in a random order (Sirigu et al., 1996). The authors found that frontal patients again made more sequencing errors, introduced irrelevant actions from one script to another and had more difficulty in discarding distractors as compared to controls.

The hypothesis of the present study is that the planning impairment in TBI patients is related specifically to frontal dysfunction. If this is the case, we expect TBI patients to

behave in the script tasks similarly to patients with focal prefrontal lesions as shown by Sirigu et al. (1995, 1996). In contrast, if their planning disorder is the result of a deficient activation of low-level routine skills, an impairment for every aspect of script processing should be found.

METHODS

Research Participants

Since the aim of this study was to assess the effect of diffuse traumatic brain damage on script knowledge, only patients who had suffered a severe high-velocity injury, but without any focal cortical contusion on CT and/or MRI scans were included. The patient group included 12 patients (7 males) at the subacute stage (6 months or more). They all had sustained a severe traumatic brain injury, as defined by an initial score of 8 or less at the Glasgow coma scale (GCS). They were recruited from a consecutive sample of patients referred to a rehabilitation unit for neuropsychological assessment and/or rehabilitation. Mean age was 28.7 ± 8.6 years, mean education duration 13.5 ± 3.8 years, mean GCS score 5.6 ± 1.5 , mean coma duration 16.0 ± 7.3 days and mean posttraumatic amnesia (PTA) duration 2.7 ± 1.7 months. All patients had PTA duration of 3 weeks or more (PTA duration was not available in 1 case). Mean time since injury was 72.7 ± 46.0 weeks. Patients were informed of the experimental aim of the study and gave their consent to participate. None of the patients presented with aphasia or alexia. They were compared to a group of 12 healthy controls (9 males) matched for age and education duration (M age: 29.3 ± 10.8 years; M education duration: 13.5 ± 4.0 years). All controls were free of previous neurological or psychiatric disorder.

Procedure

Script reconstitution and script generation procedures were performed according to a methodology described previously (Sirigu et al., 1995, 1996).

Script reconstitution

In our study this task was always performed first and involved three different conditions of increasing difficulty. In each condition, subjects were presented with an array of 20 cards with an action written on each one. They were requested to sort the cards according to the scripts they belonged to and according also to their order of execution. The different conditions were as follows:

- A. *Scripts with headers.* The twenty actions belonged to four different scripts, with each header written on separate cards and displayed in front of the subject throughout the task. There were five actions per script, but this was not stated explicitly to subjects.

- B. *Scripts with distractors*. This was similar to condition A but four irrelevant actions considered as distractors were included among the 20 cards. As a result, there were only four correct actions per script. Subjects were informed of the possibility that some actions could be irrelevant to the scripts and should be discarded.
- C. *Scripts without headers*. This was similar to Condition A but no script header was provided. Subjects were not informed of the number of scripts presented, and were asked to label each script they could find.

All subjects received conditions A, B, and C, in this order. No time limit was given, but subjects were asked to perform the task as fast as possible, and task duration was recorded. All scripts were routine activities, such as dialing a phone number, going to the theater, or toasting bread.

Script generation

Three different activities ranging in a different degree of familiarity were studied: *Routine* ("preparing to go to work in the morning"); *Nonroutine* ("taking a trip to Mexico"); *Novel* ("opening a beauty salon"). The examiner defined each activity by describing the script's starting point and its ending point, as well as the purpose or goal of the activity (e.g., "Tell all the actions you need to do if you decide to take a trip to Mexico; start from the moment you decide to take the trip until the moment you come back home"). No time limit was given, but total evocation time was recorded.

For each condition (routine, nonroutine and novel), subjects were first asked to generate the script, stating the different individual actions necessary to achieve the proposed goal. Secondly, subjects were asked to evaluate different aspects of the actions they had just generated, as follows:

- *Importance rating*: Patients were asked to rate the importance of each individual action, with respect to the script's stated goal, on a 5-point rating scale (1 = *no relevance at all*; 5 = *very important*).
- *Ordering actions in their temporal sequence*: Patients were presented with the written list of all actions they had generated, and were asked to organize actions in the sequential order that they would have executed normally.

Data Analysis

Script reconstitution

Mean duration was measured, as the time elapsed between the examiner's *go* signal and the subject report having completed the task. Four other scores were used for each condition: (1) errors of temporal ordering of actions within a script, namely, sequence errors; (2) intrusions (or boundary violations), scored when a single action belonging normally to one script, was incorporated in another script; (3) distractor errors, in Condition B, when a distractor card was included into a script or when a relevant action was dis-

carded as irrelevant; (4) number of scripts found in Condition C (without headers).

Script generation

The following scores were computed for each subject and each of the three scripts: (1) total number of actions generated; (2) mean evocation time per action (total evocation time/total number of actions); (3) script rule violations which included (a) closure errors (early closure, script stopping short of the stated end point, or late closure, script extending beyond stated endpoint); (b) intrusions, which were actions obviously irrelevant to achieve the given goal; (4) sequence errors, which were the total number of out-of-order actions, either in spontaneous generation or in script evaluation. Two independent raters (F.C., P.A.) scored closure, intrusion, and sequence errors. Interrater agreement was close to perfect. Two additional scores have been computed for each group: action frequency (number of subjects reporting a given action divided by the total number of subjects) and mean judgment of importance for the main central actions.

Behavioral assessment of the dysexecutive syndrome

The presence of a dysexecutive syndrome in everyday life was assessed in the patient group by two different ways. First, the therapist who best knew the patient was asked to rate a French translation of the Dysexecutive Questionnaire (DEX; Burgess et al., 1998; Wilson et al., 1996). This questionnaire covers 20 of the most commonly reported symptoms of the dysexecutive syndrome, across four broad areas of behavioral change: (1) emotional or personality, (2) motivational, (3) behavioral, and (4) cognitive. For each item, a 5-point scale was used, ranging from zero (*the trouble never happens*) to 4 (*it happens very often*). Factor analysis revealed a five-factor structure of the DEX (Burgess et al., 1998). The first three factors relate to the cognitive components of the dysexecutive syndrome (inhibition, intentionality, and executive memory respectively), while the fourth and fifth factors seem to relate, respectively, to the positive and negative emotional and personality changes.

In addition, subjects were given an executive route-finding test, which is an ecological assessment performed in a real-life environment (Boyd & Sautter, 1993). This task is similar to an usual real-world problem solving task, in which subjects have to find their way to an unknown location within the hospital. Following the methodology proposed by Boyd & Sautter (1993), a rating scale was devised, addressing the content areas of (1) task understanding, (2) information seeking, (3) retaining directions, (4) error detection, (5) error correction, and (6) on-task behavior. For each item, a four-point scale was used (ranging from 1 = *poor performance* to 4 = *normal performance*), and a global score was computed (maximal score = 24). This task was found to have high interrater reliability and

acceptable concurrent validity with other tests of executive functions (Boyd & Sautter, 1993).

The DEX and the route-finding test were scored by therapists who were blind to the results of the script tasks. For practical reasons, the DEX could not be completed in 2 patients and the route-finding in 1 patient. Control subjects were not given the DEX, which was only used for within-group comparisons.

Standard neuropsychological assessment

This included tests usually considered as sensitive to the dysexecutive syndrome: The modified Wisconsin card sorting test (Nelson, 1976), the Stroop test (Stroop, 1935), and the trail-making test (Reitan, 1958). A global assessment of intellectual functioning was performed also by means of Raven's Progressive Matrices (PM) 38 and of two verbal subtests (vocabulary and similarities) of the Wechsler Adult Intelligence Scale-Revised (WAIS-R).

RESULTS

Script Reconstitution

Duration of reconstitution

Statistical analyses were performed by means of a 2 (patients vs. controls) \times 3 (Condition A vs. Condition B vs. Condition C) repeated measures analysis of variance (ANOVA). A significant main effect of group was found [$F(1,22) = 30.2, p < .0001$], with a significant main effect of experimental condition [$F(2,44) = 3.3, p < .05$], without any significant Group \times Condition interaction [$F(2,44) = 0.2, p > .1$]. As shown on Table 1, TBI patients needed more time than controls to reconstruct scripts, in all conditions.

Sequence errors within a script

Although there was a slight trend for patients to produce more sequence errors than controls, this effect was not

statistically significant [$F(1,22) = 1.6, p > .1$] (Table 1). There was a significant main effect of condition [$F(2,44) = 6.6, p < .01$], without any significant Group \times Condition interaction [$F(2,44) = 0.3, p > .1$]. Subjects (patients and controls) made more sequence errors in Condition A.

Intrusions

Intrusions of a given action from one script to another were found only in the patient group (Table 1). No intrusion was found in the control group, whereas 5 patients (41.6%) made at least one intrusion (corrected chi-square = 4.0, $p < .05$). The number of intrusions did not significantly differ in the three experimental conditions.

Distractor errors (Condition B)

There was no significant difference between patients and controls [$F(1,22) = 0.02, p > .1$]. Four patients and 6 controls failed to discard at least one irrelevant action. Moreover, 9 patients and 7 controls discarded erroneously at least one relevant action (Table 1).

Number of scripts reconstituted (Condition C)

There was no significant difference between groups (Table 1). Both patients and controls produced four scripts and all of them, except 1 patient, labelled them correctly.

Script Generation

Number of actions generated

Statistical analyses were performed by means of a 2 (patients vs. controls) \times 3 (routine vs. nonroutine vs. novel) repeated measures ANOVA. There was no significant main effect of group [$F(1,22) = 0.01, p > .1$]. A significant effect of condition was found [$F(2,44) = 6.6, p < .01$], without significant Group \times Condition interaction [$F(2,44) = 0.2, p > .1$]. As shown on Table 2, both groups generated fewer actions under novel condition.

Table 1. Script reconstitution

	Patients			Controls		
	A <i>M (SD)</i>	B <i>M (SD)</i>	C <i>M (SD)</i>	A <i>M (SD)</i>	B <i>M (SD)</i>	C <i>M (SD)</i>
Time (min)	3.4 (0.9)	3.8 (1.2)	4.0 (1.4)	1.8 (0.5)	1.9 (0.5)	2.1 (0.6)
Sequence errors	1.4 (1.7)	0.5 (0.7)	1.0 (0.9)	1.1 (0.9)	0.2 (0.4)	0.4 (0.6)
No. of subjects	8/12	5/12	7/12	9/12	3/12	4/12
Intrusions	0.08 (0.3)	0.2 (0.4)	0.33 (0.6)	0	0	0
No. of subjects	1/12	3/12	3/12	0/12	0/12	0/12
Distractor errors (B)		1.7 (1.2)			1.8 (1.7)	
No. of subjects		10/12			9/12	
Number of scripts (C)			4.0 (0.0)			4.0 (0.0)

Note. Performance in each group, under the three experimental conditions. The table presents the means and standard deviations in brackets, and the number of subjects who committed at least one error.

Table 2. Script generation

	Patients			Controls		
	Routine <i>M (SD)</i>	Nonroutine <i>M (SD)</i>	Novel <i>M (SD)</i>	Routine <i>M (SD)</i>	Nonroutine <i>M (SD)</i>	Novel <i>M (SD)</i>
Number of actions	17.1 (16.3)	18.2 (9.7)	8.6 (3.9)	17.3 (11.1)	15.9 (5.4)	10.0 (3.4)
Evocation time/action	0.7 (0.2)	0.7 (0.2)	0.8 (0.3)	0.4 (0.1)	0.5 (0.2)	0.6 (0.2)
Closure errors	0.7 (0.5)	0.7 (0.5)	0.5 (0.5)	0.1 (0.4)	0.3 (0.50)	0.5 (0.5)
No. of subjects	8/12	8/12	6/12	2/12	4/12	6/12
Intrusions	0.0 (0.0)	0.0 (0.0)	0.1 (0.3)	(0.0) (0.0)	(0.0) (0.0)	0.2 (0.5)
No. of subjects	0/12	0/12	1/12	0/12	0/12	1/12
Sequence errors	1.4 (1.7)	0.5 (0.6)	1.0 (0.9)	1.1 (0.9)	0.2 (0.4)	0.4 (0.6)
No. of subjects	8/12	5/12	7/12	9/12	3/12	4/12

Note. Performance in each group, under the three experimental conditions. The table presents the means and standard deviations in brackets, and the number of subjects who committed at least one error.

Mean evocation time per action

Time taken to generate a single action was significantly longer in the patient group [$F(1,21) = 9.7, p < .01$; one missing data in the patient group; Table 2]. There was a marginally significant main effect of condition [$F(2,42) = 3.1, p = .054$] without any significant Group \times Condition interaction [$F(2,42) = 0.5, p > .1$]. Subjects (both patients and controls) needed slightly more time per action under novel condition.

Closure errors

These errors were scored dichotomously (*yes/no*) in each condition and for each patient. Eleven out of 12 patients committed one or more closure errors, while this was observed in only 8 controls (chi-square = 8.0, $p < .05$; Table 2). The group difference was significant only in routine condition (corrected chi-square = 4.3, $p < .05$). Closure errors mainly consisted of late closures (2/3) rather than early closure errors (1/3).

Intrusions errors

There was no significant difference between patients and controls. Only 1 patient and 1 control committed at least one intrusion, under novel condition (Table 2).

Sequence errors

No significant main effect of group was found, neither in spontaneous generation, nor in script evaluation [$F(1,22) = 1.6$ and 0.2 respectively, both $ps > .1$]. One or more sequence error occurred in 10 patients and 8 controls in spontaneous generation (Table 2), and in 2 patients and 5 controls in script evaluation.

Action frequency

Evocation frequency varied greatly from one action to another: some actions were stated by all subjects, some others by only 1 or 2 subjects. In order to assess whether patients

and controls reported each action with similar frequencies, we first classified the actions generated by the control group into categories (e.g., preparing coffee or making toast fell into the “breakfast” category). We obtained a total of 32 categories (8 for routine, 14 for nonroutine and 10 for novel condition). Subsequently, we asked two independent judges to rate whether patients’ actions belonged to the selected categories. Then, action frequency for patients and controls was compared for each of these action categories by chi-square corrected tests. No statistically significant difference was found for any category (chi-square ranging from 0 to 3.8, all $ps > .05$). Moreover, the correlation coefficient of action frequencies between both groups was high ($r = .85, p < .0001$).

Mean judgment of importance

Importance judgments were compared on each one of the 32 action categories mentioned previously, by Mann-Whitney tests. No significant difference was found between patients and controls.

Behavioral Assessment of the Dysexecutive Syndrome

Dysexecutive questionnaire

As expected, the DEX revealed behavioral difficulties in everyday life. Four items out of 20 obtained a mean score of 2/4 or more in the patient group: planning problems ($M = 2.9/4, SD = 0.9$), lack of insight and social awareness (2.8 ± 1.1), apathy and lack of drive (2.3 ± 0.9), and poor decision-making abilities (2.2 ± 0.9). The mean scores of the five factors that have been identified in a previous factor analysis of the scale have been computed by averaging the scores of each of the component items (Burgess et al., 1998). Factor 2 (intentionality), including items related to the creation and maintenance of goal-directed behavior, obtained the highest ranking (Table 3).

Table 3. Behavioral assessment

	Patients <i>M (SD)</i>	Controls <i>M (SD)</i>
Dysexecutive questionnaire (<i>n</i> = 10)		
Factor 1 (inhibition)	1.3 (0.7)	
Factor 2 (intentionality)	2.2 (0.6)	
Factor 3 (executive memory)	1.2 (0.9)	
Factor 4 (positive affect)	1.5 (0.7)	
Factor 5 (negative affect)	2.1 (0.7)	
Route-finding test (<i>n</i> = 11)		
Task understanding	3.8 (0.6)	4.0 (0.0)
Information seeking	3.2 (0.9)	3.8 (0.6)
Retaining directions	2.9 (1.0)	3.8 (0.4)*
Error detection	3.1 (0.9)	3.9 (0.3)*
Error correction	3.3 (0.8)	4.0 (0.0)*
On-task behavior	3.9 (0.3)	4.0 (0.0)
Total score	20.2 (3.4)	23.5 (1.0)**

Note. Mean (standard deviation) scores of the five main factors of the Dysexecutive questionnaire (Burgess et al., 1998) and of the performance in the route-finding test (Boyd & Sautter, 1993).

* $p < .02$; ** $p < .01$.

Route finding test

The overall performance of the patient group was significantly impaired in comparison to controls, who obtained a nearly perfect performance (M global scores: patients = 20.2/24 \pm 3.4; controls = 23.5/24 \pm 1.0, $p < .01$). Patients were significantly impaired in the following subscores: retaining directions, error detection, and error correction (Table 3).

Standard Neuropsychological Assessment

Statistical analyses were performed by means of one-way ANOVAs. Results are given in Table 4. Patients performed significantly poorer than controls on both forms of the trail-

Table 4. Performance in baseline neuropsychological tests

	Patients <i>M (SD)</i>	Controls <i>M (SD)</i>
PM 38	115.1 (9.6)	122.5 (8.6)
Vocabulary (WAIS-R)	9.7 (2.7)	10.5 (2.6)
Similarities (WAIS-R)	11.1 (2.9)	11.2 (2.1)
TMT-A	57.4 (30.5)	29.2 (9.7)**
TMT-B	121.0 (50.9)	62.5 (17.3)**
Stroop (interference condition)	34.8 (9.6)	46.4 (12.1)*
WCST (perseverative errors)	0.4 (0.9)	0.6 (1.3)
WCST (total number of errors)	3.2 (3.9)	1.9 (2.5)
WCST (number of categories)	5.7 (0.6)	6.0 (0.0)

Note. PM = Raven's Progressive Matrices; WAIS-R = Wechsler's Adult Intelligence Scale-Revised (age-scaled scores); TMT = trail-making test; WCST = modified Wisconsin Card Sorting Test.

* $p < .02$; ** $p < .01$.

making test, and on the Stroop test. There was a trend ($p = .06$) for a poorer performance on Raven's Progressive Matrices (without time limit). No significant differences were found for the Wisconsin Card Sorting Test and for verbal abilities as assessed by the two subtests from the WAIS-R.

Correlation Analysis

The performance on the script task has been compared to behavioral assessment. To minimize type I error on multiple correlations, we selected for this purpose a limited number of variables from each task. For the script task, we used a compounded measure, the total number of errors across all tasks and conditions (patients = 7.5 \pm 3.2; controls = 5.7 \pm 1.9, Mann-Whitney $U' = 96.5$, tied $p = .06$). From the DEX questionnaire, we selected the mean scores of the three cognitive factors (Factors 1-3), since significant correlations were not expected with emotional modifications. Finally, the global score of the route-finding test was also selected. To account for the nonnormal distribution of performance, nonparametric statistics were used (Spearman rank correlation coefficients). As can be seen on Table 5, performance on the script task was significantly correlated with the Factor 2 of the DEX questionnaire (intentionality) and with the global score of the route-finding test.

Spearman rank correlation coefficients have also been computed between performance in the script task (total number of errors) and scores obtained in the baseline neuropsychological tests. Only one correlation was found marginally significant, with WAIS-R vocabulary subtest ($r_s = -0.41$, $p = .05$). All other correlations were nonsignificant.

DISCUSSION

The aim of the present study was to assess planning skills in severe diffuse TBI patients by means of a task assumed to have some ecological validity, and that was found previously to be sensitive to prefrontal damage (Sirigu et al., 1995, 1996). Two tasks were given. In the first (script reconstitution), subjects were asked to sort sequences of actions in the proper order, corresponding to pre-determined scripts. In the second (script generation), subjects were asked

Table 5. Correlations (Spearman's Rho) between the script task and behavioral assessment (DEX: *n* = 10; route-finding: *n* = 11)

	Script: total number of errors	
	r_s	p
DEX factor 1 (inhibition)	0.1	.78
DEX factor 2 (intentionality)	0.57	.05
DEX factor 3 (executive memory)	0.38	.21
Route-finding	-0.47	.02

Note. DEX = Dysexecutive Questionnaire (Burgess et al., 1998).

to generate all actions necessary to achieve a goal. TBI patients performed slower than controls in both tasks, whatever the experimental condition. In the reconstitution task, they made more intrusion errors (from one script to another) than controls. However, they did not make more sequencing errors (within each script), they did not introduce more distractors compared to normals, and in the condition without headers, they were able to identify the theme of the four scripts. In the generation task, their performance was in many aspects similar to controls'. They were able to generate as many actions as controls, and with the same prototypicality. They were also able to correctly order the actions, and to state whether an action was important or not to achieve the goal. The only impairment was a higher number of late closure errors (i.e., generating actions after the stated endpoint of the script). With regard to our initial hypothesis, these results were not as predicted, since they were not identical to that obtained in previous studies in patients with focal prefrontal damage (Sirigu et al., 1995, 1996). Globally, performance was clearly better in the present diffuse TBI group than in the focal frontal group. However, some aspects of performance (slowed processing and late closure errors) were impaired in the TBI group but not in the frontal group. This suggests that the difference cannot be simply attributed to more severe lesions in the frontal group. The pattern of impairment was different in both groups, suggesting that the mechanisms involved were not the same. A summary of the similarities and discrepancies between the present TBI patients and focal prefrontal patients from two previous studies (Sirigu et al., 1995, 1996) is presented on Table 6. Thereafter, we will discuss in detail our findings, in relation with those reported by these previous studies.

Table 6. Comparison between diffuse TBI (present sample) and focal prefrontal lesions (from Sirigu et al., 1995, 1996)

	TBI	Focal prefrontal
Script reconstitution		
Duration of reconstitution	*(in all conditions)	*(B and C)
Sequence errors	N	*
Intrusions	*	*
Distractor errors	N	*
Scripts without headers	N	*
Script generation		
Number of actions	N	N
Evocation time per action	*	N
Closure errors	*(late)	*(early)
Intrusions	N	N
Sequence errors	N	*
Action frequency	N	N
Judgment of importance	N	*

Note. *Corresponds to a performance poorer than the matched control group and N to a normal performance.

Slowed processing

In both experiments, TBI patients were found to perform slower than controls under all conditions, independently of task difficulty. Such a finding is in accordance with a large amount of data demonstrating a nonspecific slowing of information processing in severe TBI patients (Van Zomeren & Brouwer, 1994). These results differ from the performance of focal prefrontal patients (Sirigu et al., 1995, 1996), who were slower than controls only for conditions B and C in the reconstitution task, and who did not show a longer evocation time in the generation task as compared to controls. These contrasting results between focal prefrontal and diffuse TBI patients support the assumption that mental slowness in TBI patients is not related specifically to prefrontal dysfunction, but rather reflects a global and nonspecific slowing down of information processing, related probably to the diffuse axonal damage. These data also raise the question of speed-accuracy trade-offs. The task was self-paced, and the subjects did not receive any specific instruction about response speed. It has already been suggested that TBI patients are able to slow down their performance to increase their accuracy (Ponsford & Kinsella, 1992). Our TBI patients could have opted for such a strategy, that did not seem available to focal prefrontal patients, thus suggesting that the nature of their impairment is different.

Action knowledge

The results obtained by Sirigu and her colleagues (Sirigu et al., 1995, 1996) lead these authors to the hypothesis that there are two different cognitive modes of representing action knowledge. The first one, which is not under the control of the prefrontal cortex, is related to lexical and semantic information, and is based on temporal contiguity and semantic associations between different actions. The second, which would be dependent on the frontal lobes, uses the goal of the action and its consequences as a binding element between script and context. This would explain why patients with prefrontal cortical damage are selectively impaired in ordering actions, in assessing how actions relate to goal and in establishing priorities (Sirigu et al., 1995, 1996). The absence of sequencing error in both tasks, or of importance judgment errors in the generation task, as well as the preserved ability to discard irrelevant actions and to find out the correct number of scripts without titles in the reconstitution task, all suggest that these aspects of action knowledge were relatively well preserved in severe TBI patients. Only two error types were more frequent in the TBI group compared to controls: intrusions from one script to another in the reconstitution task and late closure errors in generation (particularly under routine condition). Whether these errors were related to specific impairments of action knowledge, or to an impairment at a different level, will be discussed in detail thereafter.

Intrusion errors (reconstitution task)

Nearly half of the patients committed intrusions from one script to another, while this error type was never found in the control group. These errors however, did not lead to completely illogical or physically impossible sequences of actions. In most cases, they could be justified on semantic grounds. However, they did not correspond to the best logical and chronological fit between an action and the different possible sequences.

These errors could be related to a deficit at a different level than that of patients with focal frontal lesions. Intrusion errors were found only in the reconstitution but not in the generation task. This suggests that, rather than being specific to the processing of events sequence (Sirigu et al., 1995), the TBI deficit may be the result of a difficulty in dealing with multiple competing sources of information. Indeed, in the generation task, patients had to generate one script at a time, whereas, the reconstitution task required the simultaneous manipulation of four different scripts. It may be assumed that the reconstitution task put a higher demand on patients' processing resources. Severe TBI patients frequently complain of a difficulty in doing two things at the same time (Ponsford & Kinsella, 1991; Van Zomeren & Van den Burg, 1985). The origin of this difficulty is debated. It seems related, at least in part, to a nonspecific slowness of information processing (Van Zomeren & Brouwer, 1994). Several studies have suggested a possible additional impairment of the mechanisms responsible for allocating attention (divided attention, switching, or working memory) (Azouvi et al., 1996; Leclercq et al., 2000; McDowell et al., 1997).

In this regard, the absence of any particular distractor effect could seem surprising. However, it may be assumed that intrusion and distractor errors do not rely on the same mechanisms. Subjects were informed that they had to discard irrelevant actions that did not fit with any of the headers. Within this context, discarding distractors relies on the ability to focus attention on predetermined criteria, and to select nonmatching stimuli. Our data are in accordance with previous studies using different experimental paradigms, which found that focused attention is preserved in TBI patients (Ponsford & Kinsella, 1992; Van Zomeren & Brouwer, 1994), while divided attention is usually severely impaired (van Zomeren & Brouwer, 1994).

One limitation should however be acknowledged. The scripts used in the present study were similar to those used in two previous independent studies (Sirigu et al., 1995, 1996), and were not counterbalanced between and within tasks. Moreover, the reconstitution was always carried out first. Consequently, the two tasks (generation and reconstitution) differed on factors other than multiple sources of information, and these other factors (such as the use of different scripts, or an order effect) cannot be completely ruled out as contributing to the findings. Nevertheless, the scripts in the reconstitution task were all depicting very familiar routine activities, and it seems unlikely that a dif-

ferent level of familiarity with the scripts could account for all the present findings.

Closure errors (generation task)

These errors were significantly higher in the patient group only for the routine script, and consisted mainly of late closure errors (patients stopping late to endpoint). They may be related to a lack of inhibitory control that would allow subjects normally to stop at a predetermined endpoint. It may be assumed that the description of a routine event activates overlearned low-threshold scripts which do not involve a high level of supervisory control, thus being more susceptible to late closure errors in patients with deficient inhibitory mechanisms. Such errors may be compared to "action slips" (Reason, 1984) in which very familiar script representations proceed automatically once started, although they do not meet the precise requirements of the current instructions. In contrast, the most common type of closure errors made by focal prefrontal patients were early closure (i.e., the last action evoked stayed short to the stated goal; Sirigu et al., 1995). This suggests that closure errors of TBI and focal frontal patients were related to distinct mechanisms. Indeed, Sirigu et al. (1995) assumed that early closure could reflect a failure in the process of "provisional plan formulation" (Shallice & Burgess, 1991) or "means-end analysis" (Duncan, 1986).

Relationship with frontal functioning

Patients in the present TBI group all suffered from a diffuse injury, without any detectable focal prefrontal injury. However, the absence of a focal frontal lesion does not mean that the frontal lobes have a normal functioning after a severe TBI. Indeed, severe TBI is commonly associated with diffuse white matter injury disrupting connections to and from the prefrontal cortex. In a recent study with PET, severe TBI patients without focal structural lesions were found to have a prefrontal and cingulate hypometabolism that was significantly correlated with cognitive and behavioral dysfunctions (Fontaine et al., 1999). A close link between performance in the script tasks and real-life executive deficits is suggested by the strong and significant correlations with the Dysexecutive questionnaire and the route-finding test (while there was nearly no significant correlation with baseline neuropsychological tests).

In this regard, how can we explain the discrepancies with the focal prefrontal patients previously reported by Sirigu et al. (1995, 1996)? The dysexecutive syndrome is not a unitary disorder and the dysfunction may greatly vary according to the site, nature, and extent of lesions (Shallice & Burgess, 1996). Such heterogeneity is supported by dissociations that have been reported between tasks assessing different aspects of executive functions both in neuropsychological studies (Shallice & Burgess, 1996) and in functional neuroimaging studies in normal subjects (Petrides et al., 1993). Our results suggest that the prefrontal dysfunction secondary to diffuse axonal injury is different in nature from that caused by cortical prefrontal lesions. Cortical

lesions seem to provoke a selective impairment of script knowledge (Sirigu et al., 1995). In contrast, problems due to diffuse axonal injury do not seem specific to script processing or to a representational impairment of action knowledge. They are best described in terms of a difficulty to deal with simultaneous competing sources of information and a lack of inhibitory control on routine overlearned skills, disorders that have been largely documented in severe TBI patients (Mattson & Levin, 1990; Ponsford & Kinsella, 1992; Stuss & Gow, 1992; Van Zomeran & Brouwer, 1994). These deficits suggest an impairment at the level of control functions which are not task-specific. The precise nature of the deficit remains hypothetical. A lack of inhibitory control and a deficit in divided attention may be related, within the Shallice (1988) model, to a dysfunction of the supervisory system which is assumed to direct attentional resources in nonroutine conditions, according to tasks requirements. However such an hypothesis would not explain why TBI patients did not show more difficulties in nonroutine conditions. An alternative hypothesis has been proposed recently by Schwartz et al. (1998), based on resource theories of attention (Wickens, 1984). These authors found that the errors made by TBI patients in simple daily-living activities were more frequent but similar in nature to that made by normal controls. They concluded that these problems could be related to a restriction in limited-capacity processing resources. This could explain why TBI patients may show difficulties in processing simple actions, such as the routine scripts in the present study. Indeed, the problems demonstrated by TBI patients in the present study did not seem related to the routine/nonroutine dichotomy, but rather to the experimental manipulation of available processing resources. This could also account for the speed-accuracy trade-off observed in the TBI group, who preferred to go slowly in order to perform accurately.

In summary, the present results suggest that patients at the subacute stage following a severe diffuse TBI have preserved access to goal representation and to some aspects of action knowledge. However, they demonstrate significant impairments when they have to deal with simultaneous competing sources of information and a lack of inhibitory control on routine overlearned skills. Such difficulties, presumably due to processing resource limitations, might explain why TBI patients fail in many elementary tasks of daily living (Schwartz et al., 1998). One limitation of the present study comes from the fact that the script tasks required only verbal description and arrangement of actions. However, a dissociation between thought (or explicit knowledge) and action has been reported frequently in dysexecutive patients. In this regard, further research should look at the actual performance of sequence of actions, in comparison to the verbal description of the scripts.

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