EXECUTIVE FUNCTIONING FOLLOWING MILD CLOSED HEAD INJURY

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ABSTRACT

This study was aimed to identify impaired attentional components in mild CHI patients. The CHI features taken into account were age (≤ 30 vs. > 30 years), loss of consciousness (yes vs. no), and time after injury (few days vs. some months). The groups tested were composed of 26 patients and 26 controls (matched for age, sex and education). Experiment 1 used a dual-task paradigm (Umiltà et al., 1992), which taps executive functions. The double task-single task difference was greater for the CHI group, but only for patients older than 30 years and/or with consciousness loss. Two years after injury, some of these patients were retested: The results showed that this deficit was still present. Experiment 2 studied visual selective attention using the Navon (1977) paradigm. In this case, there were no differences between patients and controls. The results are discussed with reference to the anterior/posterior attention systems.

INTRODUCTION

The neuropsychological evaluation of mild CHI patients is particularly difficult. Behavioural changes are rarely apparent on standard neuropsychological test batteries, and there is also evidence that returns of test scores to a normal level does not necessarily imply full recovery from trauma (Dikmen, Temkin and Armsden, 1989). The failure of neuropsychological batteries to detect cognitive deficits after mild CHI could be attributed to the fact that these batteries have been developed to detect focal and not diffuse brain damage (Gronwall, 1989). Another possible explanation is that the cognitive abilities are preserved, whereas it is the efficiency and/or the speed of processing to be impaired.

The need has arisen to find new and more sensitive testing procedures. The reaction time (RT) methodology has proven to be particularly suitable to study the cognitive deficits of CHI patients: It is precise, sensitive, allows microfunctional analysis of damaged cognitive components and easily detects malingering. Using this methodology, the evidence of cognitive deficits in mild CHI has rapidly grown (Parasuraman, Mutter and Molloy, 1991; Stuss, Stethem, Hugenholtz et al., 1989; Zanasi, Schönhuber, Gentilini et al., 1988; for a review see Gronwall, 1989).

The aim of the present study is to identify, using RT procedures, which attentional components are specifically impaired in mild CHI patients. It is generally accepted that attention is not a unitary aspect of cognition, but rather comprises a variety of interacting components. Among these components are executive processes, involving voluntary control of cognitive and motor

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behaviour (e.g., Shallice, 1988, 1994), and selective attention, involving the selection of a stimulus source(s) in the presence of competing distracting information (e.g. Allport, 1989; Umiltà, 1988a). Both components will be studied in our mild CHI patients.

To our knowledge there are very few studies specifically addressed to executive functions in mild CHI patients (see Goldstein, Levin, Presley et al., 1994). The studies on selective attention in mild CHI patients have not produced clear and consistent results. Some studies utilised the Stroop interference task (Stroop, 1935), where subjects say aloud the colour in which colours' names are printed. The stimuli can be "consistent", when the word and the colour are the same, or "conflicting", when the word and the colour are different (i.e., the word "red" printed in blue colour). Usually, the subjects are unable to ignore the words and this interferes with colour naming (i.e., slower RTs in the conflicting condition). In this task, mild CHI patients, compared to controls, show slower RTs, but the interference effect is not greater (McLean, Temkin, Dikmen et al., 1983; Van Zomeren, Brouwer and Deelman, 1984). The patients are not more distracted by the irrelevant information. A recent study (Bohnen, Jolles, Twijnstra et al., 1995) modified the Stroop to include an additional condition which adds a further conflict. Studying patients with persistent postconcussional symptoms vs those whose symptoms resolved after mild CHI, these investigators found that the symptomatic patients performed at a lower level on the modified Stroop.

Gentilini, Nichelli and Schönhuber (1989) examined a group of mild CHI patients, one and three months after the accident. The results showed significantly longer execution times in a visual search task (matrix test) (see Gentilini, Nichelli, Schönhuber et al., 1985, for similar results).

Another selective attention task, in which the subjects were asked to ignore redundant information, did not show any conclusive results (Stuss et al., 1989). The mildly concussed patients were assessed five times within the first three months after injury: within 3 days of injury, 7-10 days after injury, 14-17 days, 28-31 days, and 88-90 days. The data revealed a tendency for impaired performance, which, however, was highly variable over the five testing sessions.

A study (Shum, McFarland, Bain et al., 1990), based on Sternberg's (1969) additive-factor method, examined attentional processes in terms of four processing stages: feature extraction, identification, response selection, and motor adjustment. No evidence of impairment was found for the mild CHI patients (one patient was tested about six months after injury and the remaining six were tested about one month after injury).

In summary, the few existing studies do not allow firm conclusions. As suggested by Binder (1986), failure to find cognitive deficits after mild CHI could be due to lack of attention to intervening variables and individual differences. One of these variables is age. The older patient is at greater risk for prolonged disability (Goldstein et al., 1994; Rutherford, Merrett and McDonald, 1977, 1979: Wrightson and Gronwall, 1981), those over the age of 40 being twice as likely to have persisting symptoms than patients under the age of 30. Moreover, there is ample evidence that information processing capacity declines with age (Welford, 1958, 1962, 1980). One would expect that older people are more affected by head injury than younger people because of the progressive loss of brain tissue with advancing age (see also Gronwall, 1989). When damage is suffered after mild CHI, the older person may have less available reserves to cope with this insult.

In our study we consider the possibility of selective vulnerability related to two factors, namely age and loss of consciousness. The variable loss of consciousness has rarely been studied in mild CHI patients (see Strugar, Sass, Buchanan et al., 1993, for the absence of effect of this variable on memory performance). We hypothesised that a loss, even of only a few minutes, would affect attention, increasing cognitive impairment probability. Another variable that deserves some attention is the recovery pattern. Mild injuries show an early rapid change followed by a decelerate rate of improvement over the first or second month post injury (Gronwall, 1976, 1977, 1989; Gronwall and Wrightson, 1974). Recovery periods ranging from 1 to 3 months have been reported for some attentional skills (Gentilini et al., 1985; Gronwall and Wrightson, 1974; Hughenholtz, Stuss, Stethem et al., 1988; Levin, Mattis, Ruff et al., 1987), but the recovery pattern of executive and selective attention processes is yet unknown.

THE EXPERIMENTS

Both CHI patients and controls participated in two experiments (performed the same day). Experiment 1 tested the executive functions with a dual-task paradigm (Umiltà, 1988b; Umiltà, Nicoletti, Simion et al., 1992). Experiment 2 addressed visual selective attention and used the Navon paradigm (Navon, 1977).

Posner and Petersen (1990; also see, Posner and Dehaene, 1994) divide the attention system into subsystems that perform different but interrelated functions. The anterior attention system (anterior cingulate gyrus and basal ganglia) serves executive functions and is involved in the attentional recruitment and control of brain areas to perform complex cognitive tasks, whereas the posterior attention system (superior parietal cortex, pulvinar and superior colliculus) is largely responsible for selecting one stimulus location among many and for shifting from one stimulus to the next. Experiment 1 and Experiment 2 could thus be contrasted as tapping two different systems: the anterior (Experiment 1) and the posterior (Experiment 2) attentional systems.

The typical focal anatomo-pathological lesions after CHI are localised in the fronto-orbital cortex. Evidence suggests that the clinical symptoms of the frontal syndrome are among the prevailing long-term, and often permanent, consequences of head injury (Books, McKinlay, Symington et al. 1987; Goldberg, Bilder, Hugher et al., 1989; Grant and Alves, 1987; Luria, 1980; Oddy, Coughlan, Tyerman et al., 1985; Oddy and Humphrey, 1980; Prigatano, 1985, 1987; Stuss, 1987; Van Zomeren et al., 1984).

In contrast, as demonstrated by Robertson and her colleagues (Robertson and Delis, 1986; Robertson, Lamb and Knight, 1988, 1991; Robertson and Lamb, 1991), patients with temporo-parietal lesions show deficits in the Navon

TABLE I

Demographic and Clinical Features in the CHI Group

Ss	Sex	Age	Educ	I.Q.	GCS	CT scan	Loss of consciousness	Time
1	M	16	9	99	13	Small signs of subcortical abnormalities	Yes	159
2	F	18	13	102	15	Normal	No	184
3	M	14	9	102	15	Normal	No	170
4	M	45	6	103	14	Normal	No	104
5	M	61	8	99	15	Normal	No	80
6	M	27	8	99	15	Normal	No	97
7	M	50	5	106	15	Normal	No	113
8	M	17	11	110	15	Normal	No	145
9	F	39	12	109	13	Normal	No	76
10	M	20	13	111	15	Small signs of subcortical abnormalities	No	178
11	M	20	11	106	15	Small hyperdense area in right frontal lobe	Yes	10
12	M	32	13	107	15	Normal	No	6
13	M	20	8	85	15	Small signs of subcortical abnormalities	No	111
14	M	26	10	101	15	Normal	Yes	103
15	M	53	8	99	15	Normal	Yes	152
16	M	49	5	99	15	Normal	No	186
17	M	61	1	99	14	Normal	No	4
18	M	31	11	109	14	Normal	Yes	15
19	M	22	13	116	13	Small signs of subcortical abnormalities	Yes	137
20	M	57	8	103	15	Normal	Yes	5
21	M	45	8	111	15	Normal	Yes	2
22	M	19	8	114	14	Normal	Yes	2
23	M	15	8	109	15	Normal	No	7
24	M	59	5	99	14	Normal	No	2
25	M	28	8	92	13	Normal	No	5
26	M	17	8	109	15	Normal	No	5
		X=33,12 σ=16.42	X=8.73 σ=2,93	X=103,9 σ=7,02	X=14,5 σ=0.76			X=79,15 σ=70,12

Legend: EDUC: years of education; GCS: Glasgow Coma Scale scores (at hospital admission); CT-scan: computed tomography; Time: trauma-test interval (in days); M: Male; F: Female.

paradigm, whereas those with prefrontal lesions do not. On the base of this, we expected to find mild CHI patients' deficits in the dual-task paradigm (anterior attention system), but not in the Navon paradigm (posterior attention system).

Materials and method

Subjects

A group of 26 CHI patients and a group of 26 uninjured controls were the subjects of the experiments. Demographic and clinical data for the patients are shown in Table I.

The CHI group was selected from referrals at the Thiene Hospital using the following criteria: mild CHI, definite evidence of an acceleration-deceleration CHI, no history of previous head injury, no history of psychiatric illness, mental retardation or alcoholism, no use of drugs or medicines, no residual motor deficit, no obvious neurological deficits at the time of testing, no obvious reason for non-return to work, no seeking financial compensation for injury, no pursuing litigation, I.Q. (Wechsler, 1974) within a normal range (85 trough 116), and good recovery (a Glasgow Outcome Scale of 5; Jennett and Bond, 1975; Jennett, Snoek, Bond et al., 1981).

We defined mild CHI using a set of objective criteria (see Levin et al., 1987; Rimel, Giordani, Barth et al., 1981): a loss of consciousness of not more than 20 minutes, an admission Glasgow Coma Scale scores from 13 to 15 (GCS; Teasdale and Jennett, 1974), a duration of hospital stay (for head injury) not exceeding 24 hours, no evidence of an intracranial mass lesion such as a hematoma, no intracranial surgical procedures, and absence of complications such as meningitis.

Patients with a history of previous head injury were excluded. This was because studies of patients sustaining successive mild head injury have implicated a cumulative effect, whereby the time course of recovery is increasingly prolonged after successive insults that presumably inflict progressive diffuse axonal injury (Ewing, McCarthy, Gronwall et al., 1980; Gronwall and Wrightson, 1975).

In a careful study on neurobehavioural outcome following mild head injury, Levin et al. (1987) demonstrated that to obtain meaningful data, patients with history of previous head injury, antecedent neuropsychiatric disorder, alcoholism, or drug abuse should be excluded (or isolated). The presence of alcohol abusers and patients with previous head injuries are likely to be heavily represented in a sample of head injuries compared with controls (Binder, 1986; Rimel et al. 1981). Seeking financial compensation for injury has been proven to be highly related with the possibility of malingering (Binder, 1993).

Twenty-three patients had CHI as a result of road accidents and three of work accidents.

The control group was matched for sex, age ($M=35.17$, $SD=15.38$), and years of education ($M=9.52$, $SD=3.75$). Controls and CHI patients did not show significant differences on any of these variables (age: $t=0.45$, $p>0.05$; education: $t=1.13$; $p>0.05$).

The control patients were from the same Hospital (surgery division) and volunteered for the experiments. Those with a history of alcoholism, psychiatric disorder, mental retardation, or neurological disease were excluded. Controls were informed that their performance would provide normative data to assess the outcome of head injury.

All the participants (CHI patients and controls) were right-handed, naive as to the purpose of the experiments and had normal or corrected-to-normal vision.

EXPERIMENT 1

Executive processes are set up by subjects to attain a particular goal and are involved in many different circumstances (Shallice, 1994; Umiltà, 1988b). A paradigm that is very useful to study how executive processes operate is the one developed by Umiltà et al. (1992). In it, two tasks must be executed and the execution sequence has to be coordinated. In a previous study (Stablum, Leonardi, Mazzoldi et al., 1994), we showed that severe CHI patients incur into a disproportionate cost in the dual-task condition. The purpose of the present study was to establish whether the deficit for the dual-task condition may also be found in mild CHI patients.

Apparatus and Stimuli

The subjects sat in front of a CRT screen driven by an Apple II/e computer. The room where the experiment took place was in half-light. The approximate distance of the eyes from the screen was 40 cm.

The stimuli (1.5° × 5.5°) were placed 10° to the left or right of a central fixation point

(1° × 1°), and were displayed on the screen for 2 s. Each stimulus comprised two letters, vertically placed one above the other, which were either the same or different.

Procedure

The stimuli appeared according to a quasi-random sequence, with the constraints that there was an equal number of left- and right-side presentations and an equal number of same and different stimuli. Every trial began with the central fixation point, which stayed on the screen for 2 s., followed by the onset of the stimuli presented for 2 s., and by an inter-stimulus-interval (ISI) of 2 s.

Every subject performed two conditions (single and double task) of 144 trials each. The Single-Task condition (ST) required responding to the position (right or left) of the stimuli, pressing as rapidly as possible one of the two keys on a response panel connected to the computer. The stimulus-response mapping was compatible, that is the left stimulus required a response with the left key and the right stimulus required a response with the right key.

The Double-task condition (DT) required responding to the position of the stimuli (as in the ST condition), and then saying aloud whether the two letters were the same or different (no RT was recorded). The instructions stressed the importance of speed in pressing the correct key in the left-right discrimination, but also placed some emphasis on the accuracy of the same-different discrimination. It is important to note that in the DT condition there was no time pressure for verbal response because an interval of more than 1.5 s elapsed between the manual response and the beginning of the following trial. Furthermore, the stimuli were displayed for 2 s.

The order of the two conditions was counterbalanced across subjects (half of the subjects started with the ST condition and half with the DT condition). Both conditions were preceded by some practice trials. The experimental trials were divided into two blocks of 72 trials each, between which the subjects were allowed to take a brief rest (about 5 m).

Results

Overall, errors in the left-right discrimination task were 2.03% for the CHI group (3.21% in the ST condition and 0.85% in the DT condition) and 0.75% for the control group (0.43% in the ST condition and 1.54% in the DT condition). No error analyses were therefore carried out.

Mean correct RTs for the left-right discrimination were entered into five analyses of variance (ANOVA). The first (general analysis) contrasted performance of controls and CHI patients. The second measured ageing effects by contrasting performance of the controls and CHI patients with different ages (≤30 vs. >30 years). The third measured recovery by contrasting performance of CHI patients at baseline and 2 years postinjury. The fourth contrasted performance of CHI patients in relation with their consciousness state just after occurrence of the accident (loss of consciousness vs. no loss of consciousness). The fifth contrasted performance of CHI patients in relation with time after injury (few days vs. few months). The significance level chosen for all analyses was 0.05. Post-hoc comparisons were performed with the Scheffè method.

(A) General Analysis

Mean correct RTs for the left-right discrimination were entered into an analysis of variance with one between- and two within-subjects factors. The between-subjects factor was Group (CHI or control); the within-subjects factors

TABLE II

Experiment 1: Effects of Age. Mean Correct RTs

	CHI		Controls		Mean	
Age	≤30	>30	≤30	>30	≤30	>30
ST	425	467	391	427	408	446
DT	495	715	509	558	502	633
Mean	460	591	450	492	455	538
DT-ST	70	247	118	131	94	187

were Task (ST or DT) and Side of presentation (left or right).

The only significant source was the Task effect ($F=56.25$; d.f. = 1, 50; $p<0.0001$), showing that RT was 138 ms slower (i.e., the dual-task cost) in the DT than in the ST condition (565 vs. 427 ms, respectively).

The most interesting interaction for the purpose of this study (the Group × Task interaction) did not reach significance ($F=0.54$; d.f. = 1, 50; $p=0.446$; partial eta square = 0.011, power = 0.133). The pattern of this interaction was, however, in the predicted direction. The dual-task cost was slightly greater for the CHI group than for the control group (152 vs. 124 ms, respectively).

(B) Age

In our study, the age range was rather wide (14-61 years; see Table I). Therefore, to study age effects the subjects were divided in two groups (≤ 30 vs. >30 years). In the CHI group, 14 patients were younger than 30 ($M=21$, $SD=4.91$) and 12 were older ($M=49$, $SD=9.69$) than 30 years. The same held for the control group.

Mean correct RTs for the left-right discrimination (see Table II) were entered into an analysis of variance. The factors were as in the previous analysis, with an additional between-subjects factor, Age (≤ 30 vs. >30 years).

The main effect of Task ($F=73.84$; d.f. = 1, 48; $p=0.0001$) replicated what was found in the previous analysis. The main effect of Age ($F=9.17$; d.f. = 1, 48; $p=0.004$) reflected a slower RT in older than younger subjects (538 vs. 455 ms, respectively).

The Age × Task interaction ($F=8.40$; d.f. = 1, 48; $p=0.006$) showed that the mean RTs in the DT and ST conditions were 502 and 408 ms for the younger subjects, 633 and 446 ms for the older subjects, respectively. The dual-task cost was, therefore, greater for the older than for the younger subjects (187 vs. 94 ms).

The Group × Age × Task interaction was also significant ($F=6.32$; d.f. = 1, 48; $p=0.015$). The dual-task cost in the CHI group was 70 ms for the younger and 247 ms for the older patients, whereas in the control group it was 118 ms for the younger and 131 ms for the older subjects. The post-hoc comparisons showed that this interaction was due to a significant difference between younger and older CHI patients, the difference between younger and older controls being non-significant. Thus, patients older than 30 years showed the greatest dual-task cost.

TABLE III

Experiment 1: Dual-Task Cost (DT-ST difference) for Each CHI Patient on Test and Retest Conditions

Subjects	Test: DT-ST	Retest: DT-ST
4	47	40
5	229	229
9	235	177
15	558	467
16	211	27
17	103	333
20	300	113
21	504	381
24	240	249
Mean	270	224

(C) Recovery

Our results did not address the issue of whether, and to what extent, performance of individuals with mild CHI recovers over time. However, as said, the recovery pattern might be slower for older patients. This third analysis was therefore carried out to exclude the possibility that the greater dual-task cost in patients older than 30 years was simply due to a slower recovery after trauma.

Of the total series of 12 CHI patients older than 30 years, 9 patients returned for a follow-up examination (two years after injury). Reluctance to miss a day of work and the necessity of travelling a long distance were the chief reasons cited by patients who declined the follow-up examination.

Mean correct RTs for the left-right discrimination were entered into an analysis of variance with three within-subjects factors: Test-Retest, Task condition (ST or DT) and Side of presentation (left or right).

The significant effect of Task showed that RT was 247 ms slower in the DT than in the ST condition (742 vs. 495 ms, respectively; $F=25.71$; d.f. $=1, 8$; $p<0.001$). No other main or interaction effects were significant.

The most interesting interaction for the purpose of this analysis (the Test-Retest × Task interaction) did not reach the significance level ($F=1.15$; d.f. $=1, 8$; $p=0.314$, partial eta square $=0.126$, power $=0.159$), even though the dual-task cost was of 270 ms for the first test and of 224 ms for the follow-up (the dual-task cost for each subject on test and retest conditions is reported in Table III).

(D) Consciousness

Of the total series of 26 mild CHI patients, 9 experienced a loss of consciousness (of less than 20 minutes) and 17 did not (see Table I).

Mean correct RTs for the left-right discrimination (see Table IV) were entered into an analysis of variance with one between- and two within-subjects factors. The between-subjects factor was Group (patients with loss of consciousness, patients without loss of consciousness, and controls). The within-subjects factors were Task (ST or DT) and Side of presentation (left or right).

The main effect of Task (F=67.08; d.f.=1, 49; p=0.0001) replicated what found in the general analysis. The most interesting interaction for the purpose of this analysis (Group × Task) was significant (F=3.74; d.f.=2, 49; p=0.031), and showed that the mean RTs in the DT and ST conditions were 635 and 395 ms for the loss of consciousness group, 576 and 471 ms for the no loss of consciousness group, 533 and 409 ms for the control group. Therefore, the dual-task cost was 240, 105 and 124 ms, respectively. The post-hoc comparisons showed that this interaction is due to significant differences between the group with loss of consciousness and the other two groups.

Of the 9 patients who experienced a loss of consciousness, 5 were younger than 30 years and 4 were older than 30 years. Of the other 17 patients, 9 were younger than 30 years and 8 were older than 30 years (see Table I). Mean correct RTs for the left-right discrimination were entered into another analysis of variance. The between-subjects factors were Age (≤30 vs. >30 years) and Loss of consciousness (yes vs. no). The within-subjects factors were as in the previous analysis.

The Age × Consciousness × Task interaction approximated the significance level (F=3.08; d.f.=1, 22, p=0.093). The older CHI patients, with and without loss of consciousness, had the greatest dual-task cost: 399 and 171 ms, respectively. In the case of the younger CHI patients, without and with loss of consciousness, the dual-task cost was 45 and 113 ms, respectively.

(E) Time

Our CHI patients were tested between 2 and 186 days after injury (see Table I). Eleven were tested a few days after (M=5.72, SD=3.90) and 15 some months after injury (M=133, SD=37.78).

To study the effect of time after injury, mean correct RTs for the left-right discrimination were entered into an analysis of variance with one between- and two within-subjects factors. The between-subjects factor was Time after injury (days vs. months); the within-subjects factors were Task condition (ST or DT) and Side of presentation (left or right). No significant sources involved the Time after injury factor.

Discussion

The first analysis simply replicated the results previously obtained with normal subjects by Umiltà et al. (1992). The speeded left-right discrimination took longer when the subjects were also instructed to perform the unspeeded same-different discrimination. To explain this effect, Umiltà et al. (1992) adopted Pashler's bottleneck notion (Pashler, 1994; Pashler and Johnston, 1989) and proposed that in the critical, dual-task condition the bottleneck occurs at the decision stage. In particular, they suggested that the decision to perform the two tasks one after the other competes with the decision to execute the first response for access to the same processing stage. The extra time needed to perform the primary task in the presence of the secondary task is due to the coordination of the two tasks. Umiltà et al. (1992) argued that the structure in which the two responses are coordinated is the Supervisory System (Shallice, 1994), which is called upon under a range of circumstances, most notably when planning and decision making are required.

Mild CHI patients did not show a greater coordination cost compared to controls. When mild CHI patients have to perform two tasks, they do not seem to take much longer than controls do in planning the order of the two responses. At first sight, it seems that mild CHI does not cause a deficit in the ability to coordinate the responses. Some caution should be used, however, because the crucial Group × Task interaction was in the predicted direction (the nonsignificant result could be due to a lack of power), and other factors could be important for allowing the emergence of the effect, namely age, loss of consciousness, and time after injury.

The age analysis showed interesting effects. The age main effect suggests a slower speed of processing in older people. This result is congruent with ageing literature showing that information processing capacity declines with age (Birren, 1974; Cerella, 1985, 1991; Hicks and Birren, 1970; Salthouse, 1985; Welford, 1958). Interestingly, there is also some indication (see the Age × Task interaction) that the slowing caused by age especially affects executive functions, as indexed by the dual-task cost. The Group × Age × Task interaction shows a selective effect of aging on executive deficits after head trauma, the dual-task cost being greatest in older CHI patients (see Table II). As expected, older people are clearly more affected by mild head injury than younger people are in performing control operations. Likely, after mild CHI, older people have fewer available reserves to cope with the insult.

This result could also be due to a slower recovery in older than younger CHI patients (Gronwall, 1989; Rutherford et al., 1979; Wrightson and Gronwall, 1981). But, performance of older patients retested two years after injury did not show a clear recovery pattern over time. Thus, the greater dual-task cost of patients older than 30 years seems not to be attributable to a slower recovery after trauma. It is true that the Test-Retest × Task interaction might not have reached significance because of lack of power. However, the dual-task cost for older CHI patients tested two years after injury was still much greater than that for the younger CHI patients tested a few months after injury (224 vs. 79 ms.). Moreover the individual data do not indicate a general trend toward a recovery pattern (see Table III).

The present result thus provides evidence of persisting cognitive (i.e., executive) difficulties in mild CHI patients older than 30 years over a 2-year period. The deficit in co-ordinating two responses does not recover spontaneously, suggesting the need of developing some remedial procedure able to overcome this difficulty.

Our results also showed that even a brief loss of consciousness affects performance, increasing cognitive impairment probability (see the Group × Task interaction in the Consciousness analysis and Table IV).

The lack of significant effects attributable to time after injury (see the time analysis) is quite surprising. The literature showed evidence of cognitive deficits in the first few days after mild injury (Gronwall and Wrightson, 1974; MacFlynn, Montgomery, Fenton et al., 1984; McLean et al., 1983) and a recovery pattern

TABLE IV

Experiment 1: Effects of Loss of Consciousness. Mean Correct RTs

	CHI		Controls
Loss of consciousness	Yes	No	
ST	395	471	409
DT	635	576	533
DT-ST	240	105	124

within the first months. The present result might be related to the absence of recovery effects in our mild CHI patients retested two years after injury. The cognitive difficulties in coordinating two responses do not seem to depend on time after injury.

EXPERIMENT 2

Selective attention allows the selection of a stimulus source(s) in the presence of competing distracting information. Selective attention is involved in many different phenomena (Umiltà, 1988a): An individual may selectively attend to information presented in a particular modality, to information originating from a particular position in space, to stimuli with a particular colour or shape, or to items belonging to a particular class or category.

In the present study the Navon paradigm (1977) was used to test visual selective attention. Using this paradigm it is possible to analyze the speed of processing of global and local features and to assess the amount of interference caused by the irrelevant level (i.e., the level to which the subject should not pay attention).

Navon paradigm has been extensively used to study perceptual and attentional disorders in patients with focal lesions: The results showed local processing deficits in left-hemisphere damaged patients, global processing deficits in right-hemisphere damaged patients, and more interference in patients with temporo-parietal lesions (i.e., Alvisados and Wilding, 1982; Delis, Robertson and Efron, 1986; Doyon and Milner, 1991; Lamb, Robertson and Knight, 1988, 1990; Polich and Aguilar, 1990; Polser and Rapcsak, 1994; Robertson and Delis, 1986; Robertson et al., 1988, 1991). That is to say, there is good evidence that, in terms of Posner's (Posner and Dehaene, 1994; Posner and Petersen, 1990) anterior and posterior attention systems, the Navon task taps the posterior system.

Apparatus and Stimuli

Each subject sat in front of a CRT screen driven by an Apple II/e computer. The subject's head was positioned in an adjustable head-and-chin rest, so that the distance between the eyes and the screen was 40 cm. The stimulus was a large capital letter (global configuration: either an F or an H) made up by little capital letters (local features: either Fs or Hs). When projected on the screen, the large letter subtended 7.41° and the little letters subtended 0.57° visual angle. The large F contained 20 little letters, whereas the large H contained 23 of them.

The little letters could be the same as, or different from, the large one. When the large letter and the little letters are the same, the stimulus is said to be consistent, and when they are different the stimulus is said to be conflicting. The Fs and the Hs were selected at random with equal probabilities. Stimuli were presented for 100 ms and had a luminance of about 50 cd/m^2.

Procedure

Each subject participated individually in two experimental conditions. In the global directed condition, the subject had to decide if the large letter was an F or an H, disregarding the little letters. In the local directed condition, the subject had to decide if the little letters were Fs or Hs, disregarding the large letter. The two experimental conditions were counterbalanced, half the subjects starting with one and the other half with the other.

Each trial was preceded by a 50-ms warning beep (400 Hz). The beep started simultaneously with the onset of a fixation point at the center of the screen, which remained in the field for 500 ms. The stimulus immediately followed the offset of the fixation point and stayed on for 100 ms.

Half the subjects were required to respond to the Fs by pressing the right-side key and to the Hs by pressing the left-side key, whereas for the other subjects the letter-key pairings were reversed. Instructions stressed the importance of both speed and accuracy. Each experimental condition comprised 80 trials, divided in two blocks of 40 trials each, and was preceded by 20 practice trials. When an error occurred or RT was too long (more than 3000 ms) an acoustical feedback was given, but the presentation sequence did not stop.

Results

Overall, errors were 2.79% for the CHI group (1.78% in the global condition and 3.8% in the local condition) and 2.4% for the control group (2.45% in the global condition and 2.36% in the local condition). No error analyses were therefore carried out. Analyses similar to those performed for Experiment 1 were carried out on correct RTs.

(A) General Analysis

Mean correct RTs were entered into an analysis of variance with one between- and two within-subjects factors. The between-subjects factor was Group (CHI vs. control); the within-subjects factors were Task (global or local) and Stimulus consistency (consistent or conflicting).

The analysis showed a significant main effect of Task ($F=16.37$; d.f. = 1, 50; $p<0.0001$); RTs were 44 ms faster in the global than in the local condition (495 vs. 539 ms.). Also the Stimulus consistency main effect was significant ($F=82.70$; d.f. = 1, 50, $p<0.0001$); RTs to consistent stimuli were 31 ms faster than RTs to conflicting stimuli (501 vs. 532 ms).

Three interesting interactions did not reach significance: Task × Stimulus consistency ($F=0.79$; d.f. = 1, 50; $p=0.378$, partial eta square = 0.016, power = 0.167), Group × Task ($F=1.15$; d.f. = 1, 50; $p=0.288$, partial eta square = 0.023, power = 0.184) and Group × Stimulus consistency ($F=1.20$; d.f. = 1, 50; $p=0.279$, partial eta square = 0.023, power = 0.188).

(B) Age

An analysis was carried out to measure age effects by contrasting the performance of the control group and the CHI patients with different ages (≤ 30

vs. >30 years). Mean correct RTs were entered into an analysis of variance in which the between- and within-subjects factors were as in the previous, the only difference being a new between-subjects factor, Age (≤30 vs. >30 years).

The main effects of Task (F = 16.43; d.f. = 1, 48, p = 0.0001) and Stimulus consistency (F = 86.01; d.f. = 1, 48, p<0.0001) replicated what had been found in the previous analysis. The main effect of Age (F = 4.74; d.f. = 1, 48, p = 0.034) showed that RTs were 48 ms faster for younger than for older subjects (494 vs. 542 ms, respectively).

The more interesting interactions Age × Task (F = 0.07; d.f. = 1, 48, p = 0.790, partial eta square = 0.001, power = 0.047), Group × Age × Task (F = 1.39; d.f. = 1, 48; p = 0.245, partial era square = 0.028, power = 0.209), Age × Stimulus consistency (F = 2.70; d.f. = 1, 48; p = 0.107, partial eta square = 0.053, power = 0.364) and Group × Age × Stimulus consistency (F = 1.60; d.f. = 1, 48; p = 0.212, partial eta square = 0.032, power = 0.234) did not reach the significance level.

(C) Consciousness

The analysis contrasted the performance of the CHI patients in relation with their consciousness data (loss of consciousness vs. no loss of consciousness). Mean correct RTs were entered into an analysis of variance with one between- and two within-subjects factors. The between-subjects factor was Group (patients with loss of consciousness, patients without loss of consciousness, and controls). The within-subjects factors were as in the previous analyses.

The main effects of Task (F = 18.30; d.f. = 1, 49, p = 0.0001) and of Stimulus consistency (F = 74.18; d.f. = 1, 49, p<0.0001) replicated what was found in the previous analyses. The main effect of group was significant (F = 5.58; d.f. = 2, 49; p = 0.007); RTs were 567, 499 and 473 ms for the three groups, respectively. The post-hoc comparisons showed that this effect was due to a significant difference between the loss of consciousness group and the other two groups. The interesting interactions Group × Task (F = 1.04; d.f. = 2, 49; p = 0.361, partial eta square = 0.027, power = 0.153) and Group × Stimulus consistency (F = 0.62; d.f. = 2, 49; p = 0.541, partial eta square = 0.002, power = 0.048) did not reach the significance level.

(D) Time

To explore the effects of time after injury, mean correct RTs were entered into an analysis of variance with one between- and two within-subjects factors. The between-subjects factor was Time after injury (days vs. months); the within-subjects factors were as before. No significant effects involved the Time after injury factor.

Discussion

Experiment 2 replicated some of the results usually obtained with the Navon paradigm (see, e.g., Navon, 1977), that is, RTs were faster to global than to local letters (global advantage), and RTs to conflicting stimuli were slower than RTs to consistent stimuli (interference effect). The asymmetric interference effect, i.e. more interference in the local directed condition than in the global directed condition, did not reach significance.

The main purpose of Experiment 2 was to ascertain the presence of a deficit in visual selective attention in mild CHI patients. No evidence supported that, even if age, loss of consciousness and time after injury were taken into account. In fact the results resembled those of a previous study (Stablum et al., 1994) in which severe CHI patients, tested with the Navon paradigm some years after injury, did not show any differences from controls. It seems thus that CHI do not cause a deficit in the ability to attend to either global or local features.

The age analysis show an age main effect suggesting a generic slower speed of processing in older people. This result is congruent with the age effect found in the previous experiment and with the traditional ageing literature.

CONCLUSION

The aim of the present study was to examine executive functions and visual selective attention in mild CHI patients. Experiment 1 and Experiment 2 can be contrasted as they tap two different systems: the anterior and the posterior attentional systems, respectively (Posner and Dehaene, 1994; Posner and Petersen, 1990). The main finding of the present study can be summarised as showing a selective vulnerability for the anterior attentional system. There is a selective vulnerability within the mild CHI population, indicating that older patients and patients that have experienced a brief episode of loss of consciousness (less than 20 minutes) are more likely to show some difficulties for executive functions.

These results are interesting, especially because executive functions are crucial for assessment and rehabilitation of other neuropsychological abilities (Ben-Yishay and Diller, 1983; Lezak, 1983) and might have great effects on daily living. In addition, isolation of the factors contributing to morbidity after mild head injury is essential to develop methods of clinical managements that can prevent or at least ameliorate the trauma's sequelae (Gronwall, 1976; Rutherford et al., 1977, 1979).

The consciousness loss is often misjudged by emergency personnel (Parker, 1990), and the documentation about it is often of questionable validity. The results of this study point toward the importance of a more precise records of possible consciousness losses. Our results provide also evidence of persisting cognitive difficulties for executive processes: patients retested two years after injury still show a greater dual-task cost. The data argue against the notion that the effects of a mild concussion are only temporary and that the residual deficits will disappear spontaneously. In contrast, they strongly suggest the necessity of appropriate follow-ups after mild CHI. This practice is very rarely adopted in the clinical neuropsychological examination.

Mild CHI does not cause a deficit in the ability to attend to global or local features, even if variables such as age, loss of consciousness and time after injury are taken into account. A similar pattern of results was found in a previous study (Stablum et al., 1994). Severe CHI patients were tested some years after injury using the same paradigms. They took much longer in planning the two responses, whereas they performed like controls when selective attention was tested.

To conclude, our results demonstrate the sensitivity of RT procedures to detect cognitive difficulties in CHI patients. It should also be stressed that the mild CHI consequences we found are not likely to be overestimated. The study included an appropriate control group and used very strict screening criteria. Patients with a history of previous head injury, antecedent neuropsychiatric disorder, mental retardation, alcoholism, or drug abuse were excluded. In addition, we made sure our patients were neither seeking financial compensation nor pursuing litigation for injury.

The morbidity of mild CHI is generally underestimated and the recovery evaluation, based solely on the resolution of acute deficits and focal neurologic signs, does not take into account the deficits of higher mental functions produced. The CT scans of our patients were nearly completely negative. This confirms what is asserted in the literature: CT scans and focal neurological examinations are not sufficient for predicting cognitive and behavioural recovery (Parker, 1990; Rimel et al., 1981; but see Williams, Levin, Eisenberg, 1990, for an interesting exception). Gronwall (1989) suggested to examine, in mild CHI studies, the older patients, the patients who had a previous head injury, the patients who are high achiever or are in a demanding occupation, and the patients who have family and social stressors. Our study confirms the importance of age and adds a new category, that is the patients who incurred even a brief loss of consciousness.

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