ATTENTION AND CONTROL DEFICITS FOLLOWING CLOSED HEAD INJURY*

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It is generally accepted that attention is not a unitary aspect of cognition, but rather comprises a variety of interacting processes and functions (Allport, 1989; Parasuraman and Davies, 1984; Posner and Marin, 1985).

Major components are *selective attention*, involving the selection of a stimulus source(s) in the presence of competing distracting information (for reviews see Allport, 1989; Johnston and Dark, 1986; Umiltà, 1988a); *sustained attention/vigilance*, involving the ability to maintain attention on critical events for sustained periods of time (Davies and Parasuraman, 1982; Parasuraman and Davies, 1984); *divided attention*, involving simultaneous processing of various sources of information; *control and monitoring processes*, involving voluntary control of cognitive and motor behavior (Shallice, 1988).

Because attention is not a unitary aspect of cognition, it seems appropriate to distinguish its functions in the closed head injury (CHI) population. Only recent studies, however, were carried out within this theoretical framework (i.e., Gentilini, Nichelli and Schönhuber, 1989; Gronwall, 1987, 1989; Levin, Goldstein, High et al., 1988; Stuss, Stethem, Hugenholtz et al., 1989; Van Zomeren, Brouwer and Deelman, 1984).

Research on selective attention in CHI patients has not produced clear and consistent results. Some data (Gentilini et al., 1989) showed significantly longer execution times in a visual search task (matrix test) in a group of mild CHI patients examined one month and again three months after the accident. On the other hand, in a selective attention task carried out by Stuss et al. (1989) data were not conclusive: the confused criterion of patient selection may have affected the results. A study of spatial selective attention using Posner's paradigm (Cremona-Meteyard, Clark, Wright et al., 1992), found that the CHI group (11 patients who had suffered a moderate or severe CHI at least one year previously) showed normal cost but hardly any benefit, thus indicating that the normal capacity to pre-align attention with a cued location was impaired. An alternative explanation could be that CHI patients had difficulty in interpreting a cue as a signal to orient attention.

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Buchtel (1987) has suggested that a vigilance task may be "ideal for determining the degree of attention deficit in patients after head trauma, even with minor damage" (p. 373-374). Up to now, however, patient selection criteria as well as evidence from the few existing studies have not been consistent (Brouwer and Van Wolffelaar, 1985; Denker and Lofving, 1958; Ewing, McCarthy, Gronwall et al., 1980; Gentilini et al., 1989; Newcombe and Ratcliff, 1979; Parasuraman, Mutter and Molloy, 1991; Stuss et al., 1989; Van Zomeren and Brouwer, 1987; Van Zomeren et al., 1984).

Likewise, the very few studies explicitly taking into account divided attention in CHI patients used quite heterogeneous patient selection criteria, making results interpretation particularly difficult (Gentilini et al., 1989; Gronwall, 1977; Gronwall and Wrightson, 1981; Miller, 1970; Stuss, Ely, Hugenholtz et al., 1985; Stuss et al., 1989). Even so, divided attention seems to be the most damaged ability after trauma. To our knowledge there are no studies specifically addressed to the control and monitoring processes in CHI patients.

The general aims of the present study were: a) to assess residual deficits in patients with post-concussion symptoms; b) to identify which attentional components are specifically impaired in CHI patients. We investigated the effect of severe CHI on two components of attention: a) control and monitoring processes and b) selective attention. The issue addressed was whether severe CHI leads to a specific impairment in these attentional components. The rationale underlying the present study was that CHI patients could present a frontal-lobe-like clinical picture (Goldberg, Bilder, Hughes et al., 1989; Luria, 1980; Van Zomeren et al., 1984), even if there is no evidence of frontal lobe lesions (Stuss, 1987). 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; Grant and Alves, 1987; Oddy, Coughlan, Tyerman et al., 1985; Oddy and Humphrey, 1980; Prigatano, 1985, 1987).

THE EXPERIMENTS

Both the CHI patients and the controls participated in three experiments. The CHI patients performed the three experiments over three days, while the controls completed them in one or two days. Experiments 1 and 2 focused on the monitoring and control functions. According to Norman and Shallice model (1986), cognitive and behavioral skills are stored in memory as schemata, which are activated whenever the critical internal and external conditions arise. Their model posits two levels of control processes. At the lower level, contention scheduling, the most activated schemata take control of behavior and inhibit all the incompatible ones. An effortful but more flexible mode of control takes place through the Supervisory Attentional System (SAS). The SAS rearranges separate schemata in new sequences when a new task is to be performed; it inhibits or activates schemata other than the ones most closely linked with a certain environmental situation (a top-down control of behavior), and plays a crucial role when new skills have to be learned. The view that control of behavior can be decided not only by bottom-up schema activation, but also by top-down control processes and specific attentional mechanisms, is maintained also by other current theories (e.g., Pascual-Leone, 1987).

Both experiments involved a double task. In one experiment the same stimulus required either one or two responses, depending on the experimental conditions. The need for response coordination in the double task condition causes a longer reaction time (RT) than in the single task condition (Umiltà, 1988b; Umiltà, Nicoletti, Simion et al., 1992). In the second experiment, different stimuli required different responses, the subject having to switch from one task to the other. The switch causes a lengthening of RT (Morra and Roncato, 1986). Both coordination and shifting are thought to involve high-level control processes, such as those attributed by Norman and Shallice (1986) to the SAS. Experiment 3 addressed visual selective attention and used the Navon paradigm, in which subjects are required to selectively attend the global and local features of a visual configuration (Navon, 1977). When the features at the two levels are conflicting, there is an interference, indexed by longer RTs.

Method

Subjects

A group of 14 CHI patients, selected out from a total of 24, and a group of 14 controls were the subjects of the experiments. The CHI group was selected from referrals to the Psychological Service at the Bolzano General Hospital using the following criteria: no younger than 20 or older than 60 years, definite evidence of an acceleration-deceleration CHI, no residual motor deficit, no obvious neurological or neuropsychological deficiency at the time of testing[1], no obvious reason for non-return to work, no history of previous head injury or psychiatric illness requiring treatment, no use of drugs or medicines, good recovery. The Glasgow Outcome Scale (GOS; Jennett, 1975; Jennett and Bond, 1975; Jennett, Snoek, Bond et al., 1981) was used as an index of recovery, and all the subjects scored 5, meaning good recovery, except one (patient BM) who scored 4, i.e. mild deficits. Despite the apparently good recovery, all the patients continued to have poorly defined complaints, such as difficulty in concentration and memory, fatigue, irritability, and difficulty in performing tasks as well as before trauma (some of them had not resumed work; see Table I: RTW scale; Cfr. Van Zomeren and Van den Burg, 1985). These complaints initiated the referral for neuropsychological assessment.

At the time of accident, the patients had severe CHI (11 as a result of road traffic accidents; 2 of fall, and 1 of sports accident) according to the Glasgow Coma Scale (GCS; Cfr. Teasdale and Jennett, 1974; see Table I). In the CHI group, testing was carried out between 6 and 127 months after injury (M=42, SD=39.67) (see Table I). The Control group was matched for sex, age (M=31, SD=9.92), and years of education (M=10.78, SD=2.86). Control subjects and CHI did not show significant differences on any of these variables (age: t=0.19, p=0.853; education: t=−1.32, p=0.2). The Control subjects willingly participated in the experiments. Seven of them were attending a handicap assistant course. All the subjects (CHI patients and controls) were right-handed, naive as to the purpose of the experiments, and had normal or corrected-to-normal vision.

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[1] The CHI subjects had been administered a number of tests for purpose of neuropsychological assessment: Tower of London, Wisconsin Card Sorting Test (WCST), Stroop test, Attentional Matrix, Mental Control (WMS subtest n° 3), Digit-Symbol (WAIS subtest n° 7), Raven, Block Design (WAIS subtest n° 9), Object Assembly (WAIS subtest n° 8), Elithorn's perceptual maze test, Figure's Copy by Rey-Osterrieth, Categorical Verbal Fluency, Verbal Span, Digit Span (WAIS subtest n° 5), Paired Words Memory Test (WMS subtest n° 3), Story Memory Test (Spinnler and Tognoni, 1987). These tests showed no gross impairment in neuropsychological functioning at the time of testing.

TABLE I

Demographic Features in the CHI Group

Name	Sex	Age	Educ.	Time	Early CT-scan	Control CT-scan	GCS	RTW
BM	M	33	8	15	Epidural haematoma left temporo-parietal	Small hypodense area	3	4
FC	M	19	8	8	Right frontal extradural haematoma	Mild signs of right temporal abnormalities (EEG)	3	4
GC	F	25	8	24	Suspect left frontal igroma	Absorbed left frontal igroma	4	0
ME	M	57	11	6	Small right frontal haematoma	Normal	8	4
MR	M	26	8	91	Normal	Normal	8	1
PP	M	32	11	127	—	—	3	3
RJ	M	45	5	25	Left temporo-parietal haematoma	—	5	4
RiJ	M	22	10	21	—	—	3	2
RL	F	29	8	113	Mild left fronto-parietal lesion	Normal	8	1
RR	M	25	11	15	Bilateral multiple foci; diffuse haedema	Small subcortical lesions in right temporo-parietal area	3	3
SR	M	26	13	51	Subdural haematoma	—	3	3
SP	M	34	11	49	Large hypodense area in right parieto-occipital area	Small left subdural igroma	8	4
SeR	M	43	8	19	Temporal lobes bilateral haemorrhage	—	8	0
ZN	F	30	13	29	—	—	3	0
Mean		32	9.5	42			5	2

Legend: Educ.: years of education; Time: trauma-test interval (in months); GCS: Glasgow Coma Scale; RTW: return-to-work scale (Van Zomeren, Van den Burg, 1985); 0 = former work or study resumed without any changes; 1 = former work resumed, but with lower demands, for example part-time or at a lower rate; 2 = former work not resumed; working at a lower level; 3 = working in a socially sheltered environment; 4 = not working at all.

Experiment 1

Rationale

Our aim was to identify if there was a specific deficit for the CHI patients in a task that requires coordination of two responses. We hypothesized that the CHI patients would show a greater RT lengthening.

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 seconds. Each stimulus comprised two letters, vertically placed one above the other, that 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 seconds, followed by the onset of the stimuli presented for 2 seconds, and by an inter stimulus interval (ISI) of 2 seconds.

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. 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 sec elapsed between the manual response and the beginning of the following trial. Furthermore, the stimuli were displayed for 2 sec.

The order of the two conditions was counterbalanced across subjects. 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 (no more than 5 minutes).

Results

Overall, errors in the left-right discrimination task were 0.91% for the CHI group and 0.57% for the Control group. No error analyses were therefore carried out.

Mean correct RTs for the left-right discrimination were entered into an analysis of variance (ANOVA) with one between- and two within-subjects factors. The between-subjects factor was Group (CHI or Control); the within-subjects factors were Task condition (ST or DT) and Side of presentation (left or right). The significance level chosen for this and all subsequent analyses was

TABLE II

DT-ST Difference for Each Subject

CHI	DT-ST	Control	DT-ST
BM	356	EM	27
FC	104	CDV	242
GC	209	CP	26
ME	402	ML	78
MR	124	NR	3
PP	162	MU	−12
RJ	213	GC	128
RiJ	134	SL	44
RL	235	RV	106
RR	−78	MF	46
SR	438	BM	99
SP	331	SM	121
SeR	27	CF	87
ZN	106	ZG	125
Mean	197		80

0.05.

The main effect of Task showed that RT was 138 ms slower in the DT than in the ST condition (F=42.05; d.f.=1, 26; $p<0.0001$) (549 vs. 411 ms, respectively). The left-right discrimination took longer when the subjects were also required to perform the unspeeded same-different discrimination. The main effect of Group (F=21.22; d.f.=1, 26; $p<0.0001$) reflected a slower RT in CHI patients (583 vs. 377 ms, respectively).

Of the three significant effects, the most interesting for the purpose of this study was the Group×Task interaction (F=7.53; d.f.=1, 26; $p<0.011$). The mean RTs in the DT and ST conditions were 682 and 485 ms for the CHI patients, 417 and 337 ms for the controls, respectively. The DT-ST difference was greater for the CHI group than for the Control group (197 vs. 80 ms; the DT-ST difference for each subject is reported in Table II).

Discussion

Experiment 1 was successful in replicating 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.

As demonstrated by Umiltà et al. (1992) the extra time needed to respond to the location discrimination in the presence of the shape discrimination is due to the coordination of the two tasks. The location response in Experiment 1 was not delayed because of the presence of the second task, but rather because location and shape information was available at the same time. As a consequence, the subjects had to decide which response to emit first (about location or shape).

Umiltà et al. (1992) argued that the structure in which the two responses are coordinated could be the SAS (Norman and Shallice, 1986), which is called upon under a range of circumstances, most notably when planning and decision making are required. The results for CHI patients can be summarized as follows:

(a) CHI patients made very few errors. This is understandable if one consider that, with a stimulus exposure time of 2000 ms, accuracy is not a problem; (b) CHI patients were slower than controls. This outcome is very common in the CHI literature and will be considered in the Conclusion; and (c) CHI patients, as expected, had a much greater lengthening of RT in the double task than in the single task condition compared to controls. When CHI patients have to perform two tasks, they take much longer in planning the order of the two responses.

Experiment 2

Rationale

Another way of studying the efficiency of monitoring and control processes is through a task-shifting paradigm. The experimental situation, first devised by Morra and Roncato (1986, 1988), was as follows. The subject has to perform two tasks: recognizing, by pressing a key, where an arrow is pointing (i.e., left or right), or reading aloud a syllable. The stimuli follow each other at a fast rate: if the stimulus is an arrow, the task is a left/right discrimination; if it is a syllable, the task is reading aloud. The type of stimulus is a "prompt" for the proper processing (Hartley, 1991): unlike a prime or a cue, a prompt cannot be ignored; it is essential to responding appropriately to a stimulus. Thus, prompting should result in conscious, controlled preparation for specific processing of a stimulus. Series of two or ten arrows and series of two or ten syllables follow one another in a regular manner.

The results obtained by Morra and Roncato (1986) showed that in the long series (LS) condition, RT to the first stimulus of the series was about 150 ms slower than to all the subsequent 9 stimuli, whereas in the short series (SS) condition, the first-stimulus RT was only 20 ms slower with respect to the second stimulus.

This suggested that in the LS condition the subjects could not – it was not convenient to – count the stimuli and prepare for the task shift. In the SS condition, instead, it was easy to know when the stimuli changed (two positions and a few simple procedural schemata are well within an adult's attentional capacity; e.g. Pascual-Leone, 1987).

Under the assumption that CHI patients have difficulties in loading appropriate schemata, slow RT should be expected in the LS condition, where no preparatory action could be taken until the first stimulus of a new series appeared. Under the assumption that CHI patients have difficulties in strategic control of their performance or in maintaining the appropriate schemata activated, slow RTs should be expected in the SS condition, where preparatory action could be taken after response to the second stimulus in a series.

Apparatus and Stimuli

The subjects sat 40 cm away from a CRT screen driven by an Apple II/e computer. The room where the experiment took place was in half-light. The experimental stimuli appeared at the center of the screen. They were arrows, pointing left or right, and syllables formed by a consonant and a vowel.

Procedure

When shown the arrows the subjects had to press as fast as possible one of the two keys on a response panel connected to the computer; the stimulus-response mapping was compatible. When a syllable was shown, they had to read it aloud as fast as possible; in this case RT was recorded through a microphone voice key.

In the SS condition, the stimuli were grouped in twos (e.g. two arrows, two syllables, two arrows again, and so on), while in the LS condition they were grouped in tens (e.g., ten arrows, ten syllables, then ten arrows again, and so on). There were four blocks of 100 stimuli each per condition, shown at brief rest intervals. A subject could perform first an SS block, then an LS block, then again an SS block and so on, for a total number of 8 blocks. The order of the blocks was counterbalanced across subjects. Before the beginning of the experimental session, every subject performed two training blocks of 40 stimuli each (one for the SS and one for the LS condition).

To make sure that faster responses to the stimuli following the first one in a series were not due to a repetition effect, that is to the actual repetition of the same stimulus and response, no syllable had any letter in common with the immediately preceding one; RTs to an arrow pointing in the same direction as the previous one were discarded.

The sequence of events was as follows: every block (SS or LS) began with arrows. First a beep was sounded and after 150 ms the stimulus appeared. If no response occurred within 1500 ms a message informed the subject to be faster, or, if the wrong key was pressed, that an error had occurred. After the response, the stimulus remained on the screen for 400 ms; then the screen was cleared, and a new trial (beep-stimulus-response) started.

The experimenter took note of which vocal responses were errors, or disturbed by an irrelevant utterance or noise, and at the end of the block those responses were excluded from analyses. The subject was given feedback about the average RT at the end of each block.

Results

Overall, errors were 1.90% for the CHI group and 1.64% for the Control group and therefore no error analyses were required. Two ANOVAs were carried out on the mean RTs of correct responses. The first ($2 \times 2 \times 10$) concerned the LS condition: we considered one between-subjects factor, Group (CHI patients vs Controls) and two within-subjects factors, Task (syllable vs arrow) and Position in the series of the stimuli (position 1 to 10). The second analysis ($2 \times 2 \times 2$) had the same design but concerned the SS condition; in it, the factor Position had only two levels (positions 1 and 2).

The first analysis (LS Condition) showed that the CHI group was significantly slower than the controls (main effect of Group: $F = 25.92$; d.f. = 1, 26; $p < 0.0001$; 502 vs. 347 ms, respectively), and that responding verbally to syllables took longer than responding manually to arrows (Task main effect: $F = 222.70$; d.f. = 1, 26; $p < 0.0001$; 531 vs. 320 ms, respectively). There was a significant Position effect, due to a remarkably slower RT to the first stimulus in a series (Position main effect: $F = 98.59$; d.f. = 9, 234; $p < 0.0001$). RTs for positions 1 to 10 were 556, 411, 397, 400, 401, 412, 416, 420, 421 and 416 ms, respectively. Post-hoc comparisons (Scheffè) showed that the RT in position 1 was significantly different from those in any other position. The Group × Task interaction ($F = 8.14$; d.f. = 1, 26; $p < 0.008$) showed that the CHI patients were

TABLE III

Shifting Cost for the SS Condition for Each Subject. (The difference between the first position and the second position RT)

CHI group	SS cost	Control	SS cost
BM	77	EM	31
FC	77	CDV	47
GC	40	CP	25
ME	80	ML	8
MR	31	NR	11
PP	21	MU	−31
RJ	79	GC	27
RiJ	64	SL	27
RL	58	RV	10
RR	77	MF	5
SR	47	BM	6
SP	78	SM	48
SeR	38	CF	17
ZN	60	ZG	28
Mean	59		19

significantly slower than the controls in responding to syllables as compared to arrows. The mean RTs were 628 and 377 ms for the CHI patients, 433 and 262 ms for the controls, respectively. The Group × Position interaction was not significant ($F=0.66$; d.f. = 9, 234; $p=0.749$); partial eta square = 0.02, power = 0.32.

The analysis for the SS condition showed again a significant overall slowing of RT in CHI patients (Group main effect: $F=41.03$; d.f. = 1, 26; $p<0.0001$; 531 vs. 345 ms), and longer RTs to syllables than to arrows (Task main effect: $F=298.17$; d.f. = 1, 26; $p<0.0001$; 534 vs. 342 ms). There was also a significant main effect of Position ($F=104.57$; d.f. = 1, 26; $p<0.0001$), showing that RT to the first stimulus in a series was slower than RT to the second (458 vs. 419 ms). The Group × Task interaction ($F=8.45$; d.f. = 1, 26; $p<0.007$) showed that the CHI patients were significantly slower than the controls in responding to syllables as compared to arrows. The mean RTs were 643 and 419 ms for the CHI patients, 425 and 266 ms for the controls.

Contrary to the LS condition, a significant Group × Position interaction was found ($F=28.46$; d.f. = 1, 26; $p<0.0001$), which revealed that RT to the first stimulus of a series, with respect to the second, was slower in the CHI group than in the Control group. The mean RTs were 561 and 502 ms for the CHI patients, 355 and 336 ms for the controls. Henceforth the difference between RTs to the first and second stimulus will be called shifting cost. The shifting cost from one task to the other was 59 ms in the CHI group, while in the Control group it was 19 ms (the shifting cost for each subject is reported in Table III; all the CHI patients showed a larger shifting cost than the controls).

Discussion

Both the Task and the Position effects were significant in all the analyses. The former underlined the difference in responding to the *arrows* and to the *syllables* and the latter the longer RT to the first stimulus of every series. Morra and Roncato's (1986) results showed a shifting cost of 150 ms in the LS condition and of 20 ms in the SS condition. These results were perfectly replicated in our Control group: the shifting cost was 137 ms in the LS condition and 19 ms in the SS condition.

Because the LS condition does not allow to prepare for the new task, it may be assumed that about 150 ms is the time necessary to shift between tasks. The interval between the response to the last stimulus of a series and the presentation of the first stimulus of the next series was 550 ms. Thus, in the SS condition, there was plenty of time to complete a shifting before the stimulus appeared. Nevertheless, we found a small, but still significant, cost in responding to the first SS stimulus in the Control group (19 ms). This could mean that not all the cognitive operations could be performed before the stimulus appeared. In other words, the subject could pre-activate to a certain degree the new task-program. This was, however, not sufficient to render the task-program fully executive as also the appropriate stimulus was needed.

In the LS condition, the shift to the new program seemed entirely performed after the new stimulus had appeared. Based on the Norman and Shallice model (1986), the new program was probably performed with little intervention of the SAS, but rather with the intervention of the lower level control system (i.e., contention scheduling).

In contrast, in the SS condition the subjects could voluntarily begin the shifting operation before the stimulus appeared, and merely wait for it in order to complete the remaining operations. Of course they needed a higher level control system (the SAS) to pre-activate the task-program.

The main purpose of Experiment 2 was to investigate the task shifting mechanisms used by CHI patients. Under the assumption that CHI patients had difficulty in loading task-appropriate schemata, slow RTs should be expected in the LS condition, where no preparatory action could be taken. Surprisingly, in the LS condition no Group × Position interaction was found: the shifting cost was almost the same in the CHI and the Control group (154 vs. 137 ms, respectively). We argue, therefore, that in the presence of a relevant stimulus simple control processes, like contention scheduling, were normal in the CHI group.

Under the assumption that CHI patients had difficulty in strategic control or in maintaining activated the task-appropriate schemata, slow RTs should be expected in position 1 of the SS condition, where preparatory action could be taken. A significant Group × Position interaction was found in the SS condition: the cost paid by the CHI group was three times as large as that paid by the Control group (CHI: 59 ms; Controls: 19 ms).

In conclusion, we propose that the operations performed by the CHI patients *after* the stimulus appearance were intact. Therefore, we can say that what does not work with these patients is the processing that occurs *before* stimulus appearance. In Norman and Shallice (1986) model, this can be interpreted as an impairment of the SAS control processes, which are slower or less effective than normal. These considerations are also consistent with the findings of the first experiment.

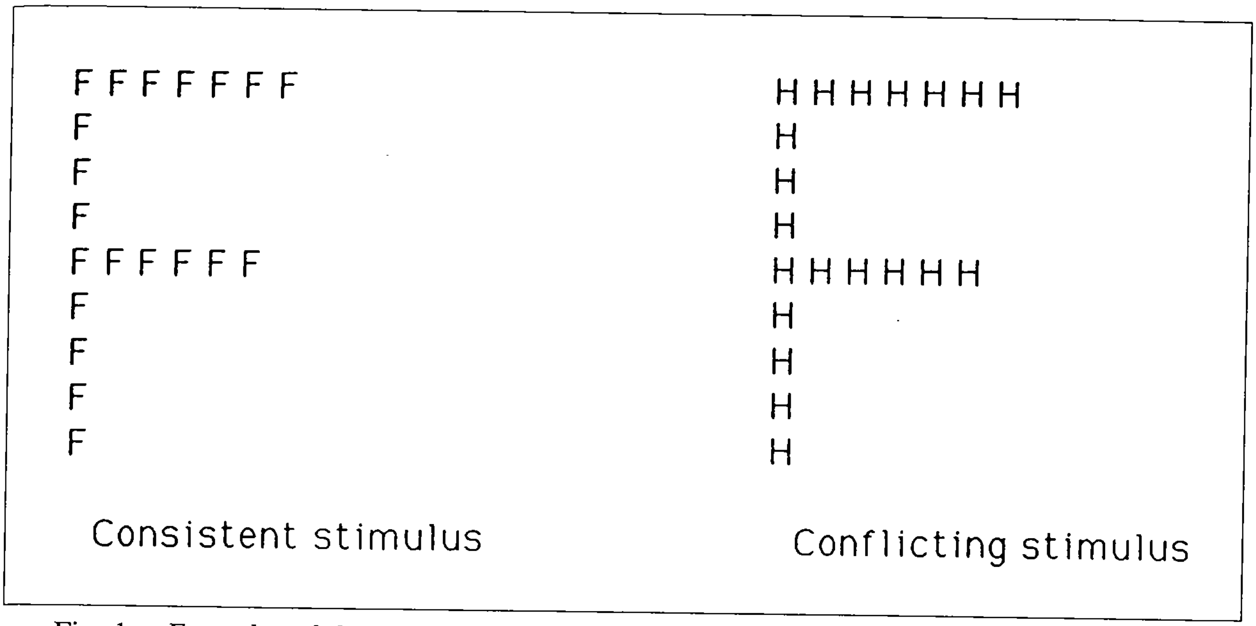

Fig. 1 – *Examples of the stimuli used in Experiment 3.*

Experiment 3

Rationale

The Navon paradigm was used to test visual selective attention. The stimuli were large capital letters made up by little capital letters. These stimuli were either consistent, when the little letters were the same as the large one (e.g., a large H formed by little Hs) or conflicting, when the little letters were different from the large one (e.g., a large H formed by little Fs). In the global directed condition, subjects were asked to focus attention on the large letter and ignore the little letters, whereas they were instructed to do the reverse in the local directed condition. Typically, RTs for global letters are faster than RTs for local letters (global advantage) and RTs to conflicting stimuli are slower than RTs to consistent stimuli, especially in the local directed condition (asymmetric interference effect).

Navon paradigm has been extensively used to study perceptual and attentional disorders in patients with focal lesions (i.e., Delis, Robertson and Efron, 1986; Doyon and Milner, 1991; Lamb, Robertson and Knight, 1988; Robertson, Lamb and Knight, 1988), but has never been used with CHI patients. If CHI patient's visual selective attention is impaired, a greater interference should be found.

Apparatus and Stimuli

Each subject sat in front of the CRT screen driven by an Apple II/e computer. The subject's head was positioned in a adjustable head-and-chin rest, so that the distance between the eyes and the screen was 50 cm. The stimulus was a large capital letter (global configuration: either F or H) made up by little capital letters (local features: either Fs or Hs) (see Figure 1). The global configuration was a 7×9 matrix, whereas the local feature was a 5 ×7 matrix. 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 letters 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. Each stimulus was followed by a visual mask. The mask consisted of fragments of little letters and remained on the screen until the subject pressed one of the response keys. RT was recorded to the nearest millisecond.

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, stayed on for 100 ms and was immediately masked. The mask remained until the subject responded or until the 2000 ms interval allowed for a response had elapsed.

Half the subjects were required to respond to the Fs stimulus by pressing the right-side key and to the Hs pressing the left-side key, whereas for the other subjects the letter-key pairing was 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 2000 ms) an acoustical feedback was given, but the presentation sequence did not stop.

Results

Two patients (FC and MR) were not able to perform one condition of the experiment (the local one), and hence were excluded from statistical analysis. The overall error rate was about 13% in the CHI group, and 10% in the Control group. No error analysis was carried out. Correct mean RTs were analyzed using a three-way ANOVA in which 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 Group ($F=12.01$; d.f. = 1, 22; $p=0.0002$): CHI patients were slower than the Control group (642 vs. 471 ms). A significant main effect of Task ($F=4.47$; d.f. = 1, 22; $p=0.046$) showed that RT was faster in the global than in the local condition (532 vs. 582 ms). Also the Stimulus Consistency main effect was significant ($F=16.08$; d.f. = 1, 22; $p<0,001$): RT to consistent stimuli was faster than RT to conflicting stimuli (544 vs. 570 ms). Two interesting interactions did not reach significance; Task × Stimulus Consistency ($F=1.85$; d.f. = 1, 22; $p=0.188$, partial eta square = 0.07, power = 0.25), and Group × Stimulus Consistency ($F=3.69$; d.f. = 1, 22; $p=0.068$, partial eta square = 0.14, power = 0.45). The results of the last interaction were in the predicted direction: the difference between consistent and inconsistent stimuli was 38 ms for the CHI patients and 13 ms for the controls.

Discussion

Experiment 3 replicated some of the results usually obtained with the Navon paradigm, 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, probably because of a lack of power.

The main purpose of Experiment 3 was to ascertain the presence of a deficit in visual selective attention in CHI patients. The results could be summarized as follows. CHI patients were slower than controls. The Interaction Group × Stimulus Consistency only approached significance level: CHI patients tended to show a larger interference effect as compared to controls and two patients could not perform the local condition.

Conclusion

This study was intended to assess two specific components of attention in CHI patients: control and monitoring functions and selective attention. The main findings of the present study can be interpreted in the framework of the control model proposed by Norman and Shallice (1986), which postulates two modes of action control. The lower, contention scheduling, allows only the most activated behavioral schemata to control the effectors and to be brought into action. Activation is caused by the appropriate environmental and internal stimuli. There is, in essence, a competition among different schemata, through inhibition of antagonistic or incompatible other schemata. It is, in Norman and Shallice's words "a horizontal mode of control". A more flexible and hence efficient control mode occurs through the SAS, which acts by increasing or decreasing the probabilities of schema activation.

The results of Experiments 1 and 2 show that CHI patients have a specific impairment in monitoring and control functions. They also suggest that efficiency of high-level control processes (i.e., the SAS) was altered. In Experiment 1, the DT-ST difference in RTs was twice as large in the CHI group as in the Control group. Previous research (Umiltà, 1988b; Umiltà et al., 1992) has shown that the DT-ST difference indexes a coordination mechanism. In other words, it points to SAS functioning.

In Experiment 2 we found a shifting cost, but only in the SS condition. In this condition the subjects are likely to have taken a conscious (willed) decision to switch to the new task, while in the LS condition the switching occurs under automatic control. That is, in the SS condition SAS intervention is likely, whereas in the LS condition contention scheduling should play the major role.

The results of Experiment 3 were not conclusive: the data suggested a larger interference in the CHI patients than in controls, but the difference only approached significance. Thus, it is difficult to say if the CHI patients have a selective mechanism deficit.

In conclusion, the present study specifies the long term consequences of CHI on attentional functioning: patients who sustained a severe CHI show deficits in control and monitoring processes, despite the apparent good recovery.

Finally a secondary issue deserves to be considered: the processing speed. In every experiment, the CHI group was significantly slower than the Control group. Almost all the literature on CHI patients reports an overall RT slowing in this population. The reasons for this generalized reduced processing speed are still unclear, although the biological rather than the functional domain seems to be involved (neurophysiological consequences of trauma, such as stretching and tearing of white matter). Research on cognitive slowing in normal population (Cerella, 1985, 1991; Salthouse, 1985, in the field of aging; Kail, 1991, in the field of development) is relevant here. Hypotheses on cognitive slowing consider mechanisms such as uniform slowing of synaptic trasmission (Birren, 1974) or information loss at each transmission. Another hypothesis invoke the role of the norepinephrine system (Foote and Morrison, 1987). The norepinephrine (NE) system arises in the locus coeruleus and projects widely through the brain, in particular to the prefrontal cortex. It appears to be a critical component of cortically mediated attentional processes, serving to sharpen the difference between signal and noise. An impairment in the NE system can be hypothesized as the cause for slowing and other changes, but it should be so particularly for tasks involving brain areas such as prefrontal cortex with projections from the locus coeruleus (Hartley, 1991). More research should be carried out attempting to recognize the mechanisms underlying cognitive slowing in CHI population. A complete account of patient's differences in processing speed will surely include both global and domain specific components.

ABSTRACT

This study was aimed at identifying the impaired attentional components in patients who had sustained a severe CHI several years before.

A group of 14 CHI patients and a Control group (matched for age, sex and education) were tested. Experiment 1 used a dual-task paradigm (Umiltà et al., 1992). The double task-single task difference was greater for the CHI group, indicating a specific damage at a central executive stage where decision are made and responses are coordinated. Experiment 2 used a task-shifting paradigm (Morra and Roncato, 1986). The cost of shifting from one task to the other was greater for the CHI group, but only in the Short Series Condition where a new task-program could be pre-activated. Experiment 3 studied visual selective attention using Navon paradigm (1977); in this case, there was no difference between patients and controls.

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