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Selective Deficit of Divided Attention Following Traumatic Brain Injury: Case Reports

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Divided attention (DA) impairment may be the most salient and commonly reported cognitive dysfunction following traumatic brain injury (TBI). Even so, DA impairment is sometimes overlooked during hospitalization. Our group experienced two TBI patients with selective deficits of DA recognized after their return-to-work. Neither patient showed abnormalities in standard tests for higher brain dysfunction. Both, however, performed poorly in a newly developed dual-task test. DA should be assessed more thoroughly and carefully in TBI patients. Dual-task testing may be sensitive in the detection of DA disturbances.

Key words: traumatic brain injury, divided attention, dual task, higher brain dysfunction, neuropsychological test

INTRODUCTION

Attentional disturbance commonly occurs following traumatic brain injury (TBI) [1]. Patients with TBI sometimes complain of difficulties in doing two things at the same time. This symptom reflects a disturbance of divided attention (DA) [2], one of the several types of attention defined (e.g., selective, sustained, alternating, and divided attention) [1]. DA is a cognitive function involving the division of available and controlled processing capacity between several cognitive operations [3]. This may involve two or more discrete tasks, or only one task that can be described as a series of subtasks [3]. DA requires the ability to integrate or organize two stimuli for processing and responding at the same time [4]. DA impairment may be the most salient and commonly reported cognitive dysfunction following mild TBI [5]. Little, however, has been reported on selective disturbance of DA among various forms of higher brain dysfunction following brain injury.

DA deficit is sometimes overlooked during hospitalization. Oftentimes the complex forms of attention such as DA are not required for the daily activities of a hospitalized patient. Paré *et al.* have emphasized the importance of paying closer clinical attention to the assessment of DA [6].

Our group treated two TBI patients who were suspected of having selective deficits of DA. Their attentional impairment was not recognized until troubles arose in their performance at the workplace. Neither patient showed any abnormalities in standard tests for detecting higher brain dysfunction. To investigate more closely, we developed a new dual-task test for DA evaluation. Here we report the results of dual-task testing for our TBI patients and discuss the significance of the test for evaluating DA.

CASE 1

The patient was a 33-year-old man who suffered a TBI in a traffic accident. He worked as a branch manager of a food manufacturing industry and had been in good health before the accident. He showed coma on admission to an acute-care-hospital. Brain images showed contusions in the bilateral frontal and temporal lobes with acute epidural hematoma. The epidural hematoma was evacuated. After acute-phase treatment (i.e, 8 weeks after injury), he was transferred to Ohta Atami General Hospital for rehabilitation. He showed no motor palsy and maintained full activities of daily living (ADL) independently. Magnetic resonance imaging (MRI: T2-weighted image) 9 weeks after the injury showed mild atrophy of the left temporal lobe (Figure).

Table 1 shows the results of standard neuropsychological tests conducted 10-12 weeks after the injury. His intelligence quotient (IQ) on the Wechsler Adult Intelligence Scale III (WAIS-III) and his memory quotient (MQ) on the Wechsler Memory Scale-Revised (WMS-R) were higher than the averages for healthy individuals: IQ 107 and MQ 135. The results of the Rivermead Behavioural Memory Test (RBMT) were also favorable. The age-corrected score of the Behavioural Assessment of the Dysexecutive Syndrome (BADS), a battery of tests for dysexecutive syndrome, was 113, higher than the average for healthy individuals. No findings strongly suggestive of attentional dysfunction were observed.

All of the results were also within normal ranges in the Clinical Assessment of Attention (CAT, described

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Table 1 Results of neuropsychological tests

	Case1 (cut-off value)*1	Case2 (cut-off value)*1
WAIS- Ⅲ		
VIQ/PIQ/IQ	116/97/107	120/113/119
WMS-R: MQ	135	113
RBMT: standardized profile score （／24）	22 (19)	24 (19)
BADS: score (age-corrected)	113 (65)	129 (65)
CAT:		
Digit Span (forward)	9 (5)	8 (6)
Digit Span (backward)	6 (4)	9 (4)
Tapping Span (forward)	7 (5)	7 (6)
Tapping Span (backward)	7 (5)	9 (5)
Visual Cancellation Task (target: a number) (correct answer) (%)	100 (98.3)*2	100 (98.2)*2
Visual Cancellation Task (target: a letter) (correct answer) (%)	96 (94.8)*2	99.1 (94.7)*2
Auditory Detection Test (correct answer) (%)	100 (96)	100 (96)
Auditory Detection Test (success rate) (%)	100 (96)	100 (96)
SDMT (accomplishment rate) (%)	60 (52)	69 (52)
Memory Updating Test (three digits) (correct answer) (%)	81 (81)	100 (88)
Memory Updating Test (four digits) (correct answer) (%)	69 (63)	100 (69)
PASAT (2s interval) (correct answer) (%)	88 (68)	93 (75)
PASAT (1s interval) (correct answer) (%)	58 (35)	65 (43)
Position Stroop Test (correct answer) (%)	100 (97)	99.1(97)

*1 A value of cut-off or below means abnormal.
*2 mean-2SD of control subjects with the same age-decade
WAIS- Ⅲ, Wechsler Adult Intelligence Scale- Ⅲ ; WMS-R, Wechsler Memory Scale-revised; MQ, memory quotient; RBMT, The Rivermead Behavioural Memory Test; BADS, Behavioural Assessment of the Dysexecutive Syndrome; CAT, Clinical Assessment for Attention, SDMT, Symbol Digit Modalities Test; PASAT, Paced Auditory Serial Addition Task

hereinafter) [7], a multi-test evaluation of attentional dysfunction (Table 1). Nor did we learn of any problems related to higher brain dysfunction in the patient's social life after his discharge from the hospital. The patient returned to work in the same company about 12 weeks after the injury. Yet at the workplace he was unable to handle a workload comparable to before. Though the content of the work was the same, there were noticeable declines in his mental processing, capacity to solve some complex problems, and ability to act promptly. As a consequence he was forced to accept a reduction in pay. The patient complained that he was only able to concentrate on one work task at a time. His subjective symptoms and performance at work suggested DA impairment.

CASE 2

The patient was a 29-year-old man who suffered a TBI in a traffic accident. He was a graphic designer who ran a private office. His job was to produce graphic designs on a PC based on the discussions and requests of his clients. He lived alone and had been healthy up to the time of the accident. He showed coma on admission to an acute-care-hospital. Brain images showed a subdural hematoma in the left posterior cranial fossa, but no other findings of note. Diffuse axonal injury was suspected. The patient was discharged 11 days after the injury. He showed no motor palsy. His gait and ADL were completely independent.

The patient returned to the same job about 6 weeks after the injury but was unable to cognitively process his work as quickly or effectively as before. As a consequence, his workload fell by 30–40% in comparison with before the injury. He said that he was unable to simultaneously concentrate on two or more issues. This suggested DA impairment.

The table 1 shows standard neuropsychological test results 8 months after the injury. His IQ on the WAIS-III, MQ on the WMS-R, and age-corrected BADS score were 119, 113, and 129, respectively. He also scored full marks in his RBMT profile. The results of the CAT subtests (described hereinafter) for the evaluation of attentional dysfunction were also far above the average for healthy individuals and no findings suggestive of attentional dysfunction were noted. An MRI performed 21 months after the injury showed no

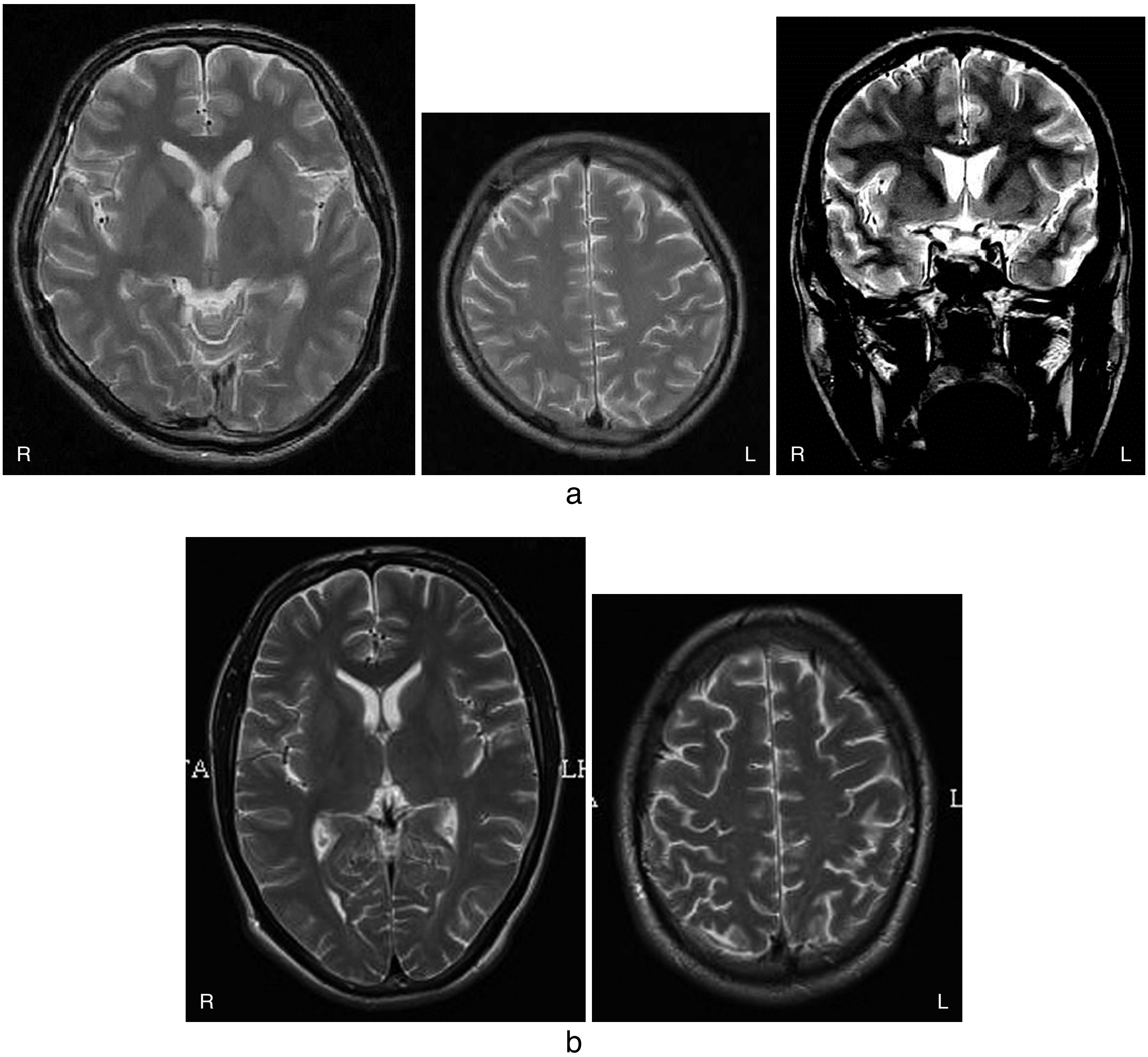

Figure MRI T2-weighted images of Case 1 (9 weeks after injury) (a) and Case 2 (21 months after injury) (b)
(a) Regions of high signal intensity and atrophy are shown in the left temporal lobe (coronal view). No significant abnormality is found in the two axial slices.
(b) No significant abnormality is found.

marked abnormal findings (Figure).

CAT (TABLE 1)

CAT was a test battery developed in 2006 by the Japan Society for Higher Brain Dysfunction to evaluate deficit of generalized attention [7].

In the Digit Span, a subject immediately recalls the raw of 2- to 9-digit figures in forward or backward order. In the Tapping Span, an assessment of visual memory, an evaluator points to 2 to 9 squares on a printed grid with 9 squares in total, and the subject then points to them in forward or backward order. The Visual Cancellation Task [8] is a simple cancellation task performed with a figure "3" and one Japanese Kana character as targets. In the Auditory Detection Test, a subject is required to respond to only one Japanese Kana character [to] out of a group of 5 characters ([to], [go], [do], [po], and [ko]) played aloud on an audio CD. The percentage of correct answers and success rate (correct answers/correct + incorrect answers) were calculated. In the Symbol Digit Modalities Test (SDMT) [9], a subject pairs figures with matching symbols shown in a series of tables, each of which includes 1 of 9 symbols matching 1 of 9 figures. The subject receives a total of 110 tests and is required to complete as many as possible over a 90 second period. The subject is assessed by the accomplishment rate (the number of correct answers/110) (%). The Memory Updating Test [10] is a difficult test requiring working memory. An evaluator reads out a row of figures and the subject is then asked to recite the last 3 digits of the row. Because the subject does not know how many figures will be presented in advance, the figures other than those specified must be deleted and the figures the subject is asked to remember must be updated. Then the subject is asked to perform a similar task, but with 4 digits instead of 3. In the Paced Auditory Serial Addition Task (PASAT) [11], a difficult task requiring working memory, the subject is asked to sum up 1-digit numbers played aloud in sequence on an audio CD. The numbers are played at 1 or 2-second intervals, and 60 numbers are played in both tests. The Position Stroop Test is a Japanese version of the task included in the Attention Process Training (APT) program developed by Sohlberg *et al.* for subjects with attentional dysfunction [1]. Three terms, namely, HIGH, MID, and LOW are randomly placed at high, middle or low locations on an original task sheet. In CAT, 114 terms are used on a grid in 6 lines (19 terms per line). The subject is asked not to read the terms aloud, but to dictate the positions of the terms, that is, "high," "middle," or "low." If the term MID is placed in the high position, for example, the subject should say "high" and not "middle." When the meaning of the term differs from the position of the term, the subject must disregard or inhibit the meaning to succeed in this task. English terms were replaced with Japanese terms, but the test was conducted identically to the English version in other respects. The subject was assessed by the correct answer rate (number of correct answers/114) (%).

DUAL-TASK TEST

Both patients performed well in the standard tests, and no evidence indicative of attentional dysfunction in social life were obtained. Even so, both patients were suspected of having DA impairment. To investigate further, we devised a dual-task test, simultaneously processing 2 different tasks, for the diagnosis of DA in these patients.

In this test, a subject simultaneously performs both a simple cancellation task and calculation (addition) by writing. In the cancellation task, an audio device plays aloud the numbers 1 to 19 in a random order, and the subject replies "Yes" whenever the target number "8" is presented. A total of 90 figures are played at 2-second intervals. The task continues for 3 minutes, and the target number "8" is played 20 times. In the calculation task, the subject calculates as many 4-digit figures as possible by writing for 3 minutes when the previous simple cancellation task completes.

The cancellation task was scored based on the correct response rate (correct answer/20) (%) and success rate (correct answer/total number of responses) (%). The calculation task by writing was scored based on the number of tasks computed, number of correct answers, and the rate of correct answers (the number of correct answers/number of tasks computed).

The performance of healthy individuals was obtained from the results of 63 volunteers (27 males and 36 females) aged 21 to 39 years (mean: 28.9 years).

DUAL-TASK PERFORMANCE OF NORMAL SUBJECTS AND THE PATIENTS

Table 2 shows the performance by Case 1, Case 2, and the healthy volunteer group. The correct response and success rate in the simple cancellation task were 100% for both patients. In the calculation task, however, Cases 1 and 2 correctly replied in only 12 and 13 out of 19 tasks computed. The correct response rates of Case 1 and 2 were 63% and 68%, respectively. The mean number of correct answers (number of tasks computed) and the correct response rate in the control group were 26.2 (28.6) tasks and 91.6%. The performance of Cases 1 and 2, therefore, was markedly poor by comparison. Neither provided as many correct answers as even the lowest-score of healthy volunteers.

DISCUSSION

Both of our patients performed better than healthy individuals in the standard neuropsychological tests. They had no problems in social life before returning to work, and no attentional dysfunction was suspected. Yet over time, emerging performance deficits in the workplace suggested their DA impairment. DA is also impaired in patients with mild TBI. Even so, no highly sensitive test to detect the impairment has been commonly adopted [6]. Central executive of working memory is thought to be involved in the expression of DA function [12], hence PASAT and Memory Updating Test are sometimes conducted to evaluate DA impairment [7]. Cases 1 and 2, however, performed well in these tests.

A new test for DA evaluation easily available on clinical practice is clearly needed. Several previous researches have used dual-task tests for assessing DA [1, 6, 12]. Combinations of different tasks involving the input and processing of visual and auditory information have also been used in APT for training patients with inattention [1]. Our group devised a dual-task test combining an auditory cancellation task and visual task for this study. Having failed to detect DA impairment in tasks with certain content, Park *et al.* found it advantageous to combine tasks using working memory or executive function [13]. Our preliminary investigation showed that dual-task composed of two complex tasks was too difficult even for healthy subjects to perform. Noting this we decided to adopt a combination of a calculation and simple cancellation tasks.

Cases 1 and 2 performed well in the simple cancellation component of our dual-task test, but they provided the markedly low number of correct answers and correct response rate in the calculation task. Even though the second task was simple, it added a level of complexity in information-processing daunting enough to decrease both the response rate and the accuracy of the responses. These results suggested that our patients' attention was limited in capacity and that their calculation processing under DT condition was impaired.

The results of a desk test may not be telling enough to predict problems in social life or at work. Thus, the emergence of impairments in social life cannot be ruled out even if the results of standard tests are within normal range. If, however, we had conducted our new dual-task test earlier, we might have been able to diagnose the DA impairment in our patients. This dual-task test appears to have clinical significance.

Several studies showed a prolongation of the task processing time by the simultaneous performance of two tasks in comparison with a single task (dual-task cost) [5, 14, 15]. This dual-task cost is often evaluated in discussions of dual-task test performance. Yet in performing a dual-task test, evidence shows that the investigators should consider the attention allocation

Table 2 Performances of dual task

	Control group (n = 63) mean (SD) range	Case1	Case2
Age	28.9 (5.2) 21–39	29	33
Cancellation task			
Correct response rate (%)	98.7 (2.4) 90–100	100	100
Success rate (%)	99.5 (2.1) 86–100	100	100
Calculation task			
Number of tasks computed	28.6 (6.6) 14–47	19	19
Number of correct answers	26.2 (6.5) 14–44	12	13
Rate of correct answers (%)	91.6 (8.5) 68–100	63	68

as well as the prolonged processing time [13]. The capacity of allocable attention is limited in the processing of multiple tasks, and trade-offs take place for the preferential allocation of attention for the maintenance of a certain process [4, 12]. Thus, the performance of other tasks often worsens. This adjustment mechanism, however, is sometimes absent in TBI patients [4, 12]. As such, the dual-task cost found in healthy individuals may be less obvious in TBI patients [2]. We therefore decided to disregard the dual-task cost in our dual-task evaluation and to instead analyze the task performance itself during the processing of the dual tasks. Future studies will be necessary to investigate which parameters are useful as indicators for the dual-task performance.

DA-related brain function sites have been investigated by functional imaging. Several studies have shown the frontal lobe to be important, but other findings differ and no consensus has been reached [16–19]. Blanchet *et al.* found memory performance impairment under a dual-task test condition in patients with mild TBI, some of whom had no abnormal findings in head images [20]. No abnormal findings in standard imaging like Case 2 cannot rule out higher brain dysfunction.

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