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# Decision-making deficit of a patient with axonal damage after traumatic brain injury

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ABSTRACT

Patients with traumatic brain injury (TBI) were reported to have difficulty making advantageous decisions, but the underlying deficits of the network of brain areas involved in this process were not directly examined. We report a patient with TBI who demonstrated problematic behavior in situations of risk and complexity after cerebral injury from a traffic accident. The Iowa gambling task (IGT) was used to reveal his deficits in the decision-making process. To examine underlying deficits of the network of brain areas, we examined T1-weighted structural MRI, diffusion tensor imaging (DTI) and Tc-ECD SPECT in this patient. The patient showed abnormality in IGT. DTI-MRI results showed a significant decrease in fractional anisotropy (FA) in the fasciculus between the brain stem and cortical regions via the thalamus. He showed significant decrease in gray matter volumes in the bilateral insular cortex, hypothalamus, and posterior cingulate cortex, possibly reflecting Wallerian degeneration secondary to the fasciculus abnormalities. SPECT showed significant blood flow decrease in the broad cortical areas including the ventromedial prefrontal cortex (VM). Our study showed that the patient had dysfunctional decision-making process. Microstructural abnormality in the fasciculus, likely from the traffic accident, caused reduced afferent feedback to the brain, resulting in less efficient decision-making. Our findings support the somatic-marker hypothesis (SMH), where somatic feedback to the brain influences the decision-making process.



## 1. Introduction

Traumatic brain injury (TBI) is a major public health problem. Although medical disabilities usually stabilize after onset, neuropsychological consequences can cause chronic handicaps that often do not receive appropriate attention and treatment (Dombovy & Olek, 1997). In particular, they show significant deficits in tasks relying on focused and divided attention (Stuss et al., 1989), on verbal memory (Crosson, Novack, Trenerry, & Craig, 1988) and on executive functions (Stuss & Gow, 1992). Executive impairments are related to planning, inhibitory control, monitoring, and mental flexibility.

Patients with TBI also have difficulties in making deliberate and advantageous decisions (Levine et al., 2005; Santoro & Spiers, 1994; Yody et al., 2000). As, after TBI, patients are often confronted with a completely new and difficult living situation, important decisions have to be made by them and their relatives. Spontaneous wrong decisions may have disastrous long-lasting consequences, such as unemployment, alienation from family and friends and legal problems, which are often linked to the disability to make adequate and advantageous choices (Warriner & Velikonja, 2006).

Damasio has proposed an influential model of human decision-making — the somatic-marker hypothesis (SMH), where he argues that somatic feedback to the brain influences decision-making in man (Damasio, 1994). It is proposed that when choosing between options that differ in relative risk, a somatic marker (e.g. a 'gut feeling') feeds back to the brain and influences decision-making. In line with this hypothesis, the reduced afferent feedback of a somatic marker to the brain would result in abnormal decision-making.

In the present study we report a patient with TBI who demonstrated problematic behaviors in situations of risk and complexity after cerebral injury due to a traffic accident. The Iowa gambling task (IGT) was used to test and confirm his deficits of the decision-making process (Bechara, Damasio, Damasio, & Anderson, 1994). To examine underlying deficits of the network of brain areas involved in his decision-making process, we compared the diffusion tensor and gray matter images of MRI between the patient and healthy control subjects. We expected that the patient would show microstructural abnormality in the fasciculus as a result of

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the traffic accident, causing reduced afferent feedback to the brain that would lead to less efficient decision-making.

## 2. Methods

### 2.1. Case report

The patient was a 30-year-old right-handed man. He had no history of alcohol or illicit drug abuse. His parents reported no family history of any major mental illness. His early childhood development was reportedly unremarkable. Before the accident, he had no significant medical problems or past psychiatric history. His personality before the accident was described by his homeroom teacher at high-school as humorous, popular, and cooperative.

At the age of 17, the patient sustained a TBI in a motorcycle accident. He was transported to a local hospital. There is no record of the Glasgow Coma Scale score, but his family reported that he fell into a coma for 6 h. The initial CT scans of the head revealed no particular change. After awakening, he was discharged to his home. According to the family, after the accident, he began to show outbursts of anger and physically aggressive behavior. He came to act recklessly and unexpectedly. He repeatedly changed his job at short intervals. He was deeply in debt and often had girl troubles.

To investigate whether traumatic brain dysfunction existed and was related to the problematic behaviors, he was referred to the outpatient psychiatry unit at our hospital for judicial psychiatric evidence. A physical examination revealed no abnormalities. He was alert, attentive and oriented. Spontaneous speech, comprehension, repetition, and naming were normal, as were calculation, mapping, praxis, right-left orientation, and finger naming. He did not have a history or present diagnosis of any axis I disorders of Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) or any neurological illness. Electroencephalography showed no relevant abnormalities.

### 2.2. Neuropsychological evaluation

#### 2.2.1. General cognitive testing (see Table 1)

A more extensive neuropsychological evaluation was performed. The patient was alert, attentive, socially appropriate, and had normal digit span performances, seven digits forward and four backward.

Intellectual functioning as assessed by Wechsler Adult Intelligence Scale-III (WAIS-III) (Wechsler, 1981) and Raven's Coloured Progressive Matrices (RCPM) (Raven, 1958) was adequate. Word fluency (Borkowski, Benton, & Spreen, 1967) was normal, and all language and language-related functions were intact. The patient had no memory deficits. Results with the Rey Auditory Verbal Learning Test-Revised (RAVLT-R) (Spreen & Strauss, 1991) and performance on the Wechsler Memory Scale-Revised (WMS-R) (Wechsler, 1987) were also excellent.

In the assessment of frontal function, the results of Frontal Assessment Battery (FAB) (Dubois, Slachevsky, Litvan, & Pillon, 2000), Wisconsin Card Sorting Test (WCST) (Berg, 1948), and Stroop test (Stroop, 1935) were normal. The Behavioral Assessment of Dysexecutive Syndrome (BADS) (Wilson, Alderman, Burgess, Emslie, & Evans, 1996) showed excellent scores. The total scores of the Dysexecutive Questionnaire (DEX) rated by the patient and his family were within normal range. However, his family rated high scores in the questionnaire of impulsiveness and aggressiveness.

#### 2.2.2. Iowa gambling task (Bechara et al., 1994)

From the patient's reports of problematic behavior after the motorcycle accident, we suspected that he had difficulty with the decision-making process due to his TBI. IGT was used to test his ability of decision-making. It consists of a computerized card game where the player is instructed to try to win as much money as possible with 100 selections from any one of four decks. The rules are not disclosed, and the player gradually learns that two of the decks are 'high risk' (A and B), i.e., intermittently produce large rewards but in the long term lead to significant financial losses, whereas two decks (C and D) lead to modest but consistent gains. Healthy individuals have previously been shown to learn to avoid the risky decks, whereas patients with decision-making difficulty process select an excessive number from the risky decks, and consequently lose money. Data analysis examined the quality of the decision-making as measured by the net score [choice of advantageous decks (C and D) – disadvantageous decks (A and B)] across five 20-trial blocks. The patient's result was compared to those of healthy male controls ($n$ = 12, age: 31.9 ± 10.5).

**Table 1**
Neuropsychological test results.

| | Patient's scores |
|---|---|
| *General intelligence* | |
| MMSE | 30/30 |
| RCPM | 35/36 |
| WAIS-R (vIQ, pIQ, fIQ) | 91, 90, 89 |
| *Memory* | |
| RAVLT-R | |
| Trials 1–5 | 7, 11, 14, 14, 14 |
| Post-interference | 13 |
| Delayed recognition | 13 |
| *WMS-R (Index)* | |
| General memory index | 101 |
| Verbal memory index | 95 |
| Visual memory index | 116 |
| Attention/concentration | 97 |
| Delayed index | 104 |
| *Frontal function* | |
| Trail making A | 25 s |
| Trail making B | 70 s |
| Frontal assessment battery (FAB) | 17/18 |
| WCST (category achieved) | 6 |
| Stroop test: word, color, word-color | 98, 82, 59 |
| BADS (index) | 118 |
| DEX (self-version, family-version) | 19, 18 |

MMSE = mini-mental state examination; RCPM = Raven's colored progressive matrices; WAIS-R = Wechsler adult intelligence scale revised; RAVLT-R = Rey auditory verbal learning test revise; WMS-R = Wechsler memory scale revised; WCST = Wisconsin card sorting test; BADS = Behavioral Assessment of Dysexecutive Syndrome; DEX = Dysexecutive Questionnaire.

### 2.3. Data acquisition of MRI

All MRI examinations were performed by 3.0-T scanner (Magnetom Verio, Siemens AG, Erlangen, Germany). DT images were acquired with echo-planar imaging (EPI) sequence (TR = 14,000 ms, TE = 84 ms, $b$ = 1000 s/mm$^2$, FOV = 256 mm, matrix = 128 × 128, slice spacing = 2 mm, slice thickness = 2 mm, averaging = 3). The reconstruction matrix was 256 × 256 matrix by interpolation, and 2 mm × 2 mm × 2 mm voxel data were obtained. Motion probing gradient (MPG) was applied in 12 directions. High-resolution three-dimensional T1-weighted images were acquired using a magnetization prepared rapid gradient echo (MPRAGE) sequence (TR = 1800 ms, TE = 2.4 ms, TI = 800 ms, flip angle = 10°, FOV × 256 mm, slice thickness = 1 mm; 208 sections in the sagittal plane; acquisition matrix, 256 × 256; acquired resolution, 1 × 1 × 1 mm). The patient's result was compared to those of healthy controls ($n$ = 13, 7 males and 6 females, age: 30.0 ± 9.5).

### 2.4. Imaging processing of MRI

Fractional anisotropy (FA) maps were generated from each individual using "dTV II" software (Masutani, Aoki, Abe, Hayashi,