Original

Evaluation of a Simple Driving Simulation for Patients with Brain Lesions, and Its Features

Yasufumi Matsuda, Noriaki Katoh, Tetsuya Okazaki, Satoru Saeki and Kenji Hachisuka

Department of Rehabilitation Medicine, University of Occupational and Environmental Health Japan

(Received: March 10, 2008)

Abstract

To examine the features of automobile driving performance in patients with brain lesions, 17 patients with a brain lesion (patient group) and 65 healthy adults (control group) were evaluated with a simple driving simulator. The cognition-reaction time, predicted time, and collision risk index of the driving simulation were then compared between the two groups, and the Pearson's correlation coefficients were obtained between the measurements and the results of neuropsychological tests and between the measurements and their driving career. The patient group showed a significantly greater mean value in the cognition-reaction time than the control group, while the patients who drove a car less than 100 km/month showed a significantly greater mean value and the standard deviation than the other patients (t-test, $p<0.05$). The standard deviation had a significantly negative correlation coefficient with the verbal IQ and full IQ of WAIS-R ($p<0.05$). The predicted time demonstrated significantly positive correlation coefficients with the verbal IQ of WAIS-R, and the verbal and visual memory of WMS-R, and PASAT ($p<0.05$). The simple car simulator may thus provide important informations regarding of driving an advice for patients with brain lesions.

(JJOMT, 56: 102—107, 2008)

—Key words—

Higher brain dysfunction, Car driving, Simulator

Introduction

Memory impairment, inattention, executive dysfunction, and other such mental deficits may be caused by a traumatic brain injury, cerebrovascular damage, hypoxic encephalopathy, encephalitis, after brain tumor surgery, and in addition to physical impairments. These higher brain dysfunctions are disincentives to returning to the society. In particular, if patients are still at a working age, they most strongly wish to drive a car upon returning to the society. So medical opinions regarding driving are often asked for by patients or their family members at medical rehabilitation clinics, and it is often difficult to appropriately respond to these questions[1].

It is necessary to evaluate properly the ability to drive in order to give an advice on recommencing a car driving, including a street driving test and a non-street driving test. Fox, et al.[2] and Tamietto, et al.[3] recommend a street driving test as an evaluation means that can most accurately predict driver's aptitude. On the other hand, a non-street driving test is advantageous in that the test can be repeated safely, even though the evaluation is limited. For non-street tests, a test using a car driving simulator as an evaluation means[4], a test mainly using neuropsychological tests[5], and a test using both[6] have been reported. In Japan, repeated instructions using a equipment that shows operation as scores on a monitor have been reported[7], in addition to a study carried out by investigating correlations between reaction times or incidence rates of accidents and neuropsychological tests[8]. However, no standardized simple simulator tests have yet been established either internationally nor domestically.

Matsunaga has invented a KM driving safety test for the purpose of educating habitual drivers with traf-

Table 1 Patients' profile

No.	Age[1)]	Interval[2)]	Disease	Paralysis	Visual field	Higher brain dysfunction
1	39	71	Traumatic brain injury	Left hemiplegia *	Full	Amnesia
2	45	7	Traumatic brain injury	None	Full	Inattention
3	20	14	Traumatic brain injury	None	Full	Amnesia
4	31	53	Traumatic brain injury	None	Full	Inattention
5	20	85	Traumatic brain injury	Right hemiplegia *	1/4 blind on upper left	Aphasia, Inattention
6	43	8	Traumatic brain injury	None	Full	Amnesia
7	47	16	Encephalitis	None	Full	Amnesia, Inattention
8	39	3	Brain infarction	Left hemiplegia *	Full	Mental deficiency
9	64	2	Brain infarction	Left hemiplegia *	Full	Dyscalculia
10	63	211	Brain hemorrhage	None	Full	Aphasia
11	36	21	Brain hemorrhage	None	Full	Dyscalculia
12	57	2	Traumatic brain injury	None	Full	Inattention, Executive dysfunction
13	37	53	Traumatic brain injury	None	Full	Amnesia, Executive dysfunction
14	69	13	Brain infarction	Right hemiplegia *	Full	Amnesia, Executive dysfunction
15	41	4	Traumatic brain injury	None	Full	Amnesia, Executive dysfunction
16	64	1	Brain infarction	Left hemiplegia *	Full	Dyscalculia
17	21	6	Traumatic brain injury	None	Full	Inattention

[1)]: at the time of the measurement (years old), [2)]: months after the onset.
*: Brunnstrom Stage of upper and lower limbs is V or VI

fic accidents and has reported a high distinction rate between drivers with accidents and those without accidents[9)]. However, it is believed that this simple driving simulator is a non-street test for driver's aptitude which is practicable in the field of medical rehabilitation but that it has not been elucidated as to whether it can be ground for giving an advice on car driving to patients with higher brain dysfunctions. Therefore, by evaluating the driving characteristics of patients with brain lesions and normal subjects preliminarily using the present simulator, the differences between patients and healthy subjects and the correlations between driving careers and neuropsychological tests were also elucidated.

Methods

The subjects consisted as followed: 17 consecutive patients (patient group, 43.3 ± 15.3 years old) with brain lesions, who had no motor paralysis or only mild motor paralysis (Brunnstrom Stage of upper and lower limbs is V or VI), were hospitalized at our department during the period from April 2006 to January 2007, compared with 65 healthy subjects (control group, 23.6 ± 1.6 years old). They were willing to cooperate with the test. The details of the group of 17 patients with brain lesions are shown in Table 1. Higher brain dysfunctions were determined using Mini-Mental State Examination (MMSE), Wechsler Adult Intelligence Scale-Revised (WAIS-R), Wechsler Memory Scale-Revised (WMS-R), Trail Making Test (TMT), Paced Auditory Serial Addition Test (PASAT), Behavioural Assessment of the Dysexecutive Syndrome (BADS), Japanese Standard Language Test of Aphasia (SLTA), and similar evaluation modalities. Moreover, the presence or absence of a driver's license, the recent average driving distance, and a history of traffic accidents after the injury were investigated. However, among the subjects in this study, the subjects who drove after an injury had no accidents other than minor accidents when parking in the garage, so the history of traffic accidents was therefore not analyzed.

The simulator consisted of few components (a special software program, a personal computer, a monitor, and a commercial steering wheel with operating buttons and game pedals,) and it conducted a cognition-response time test, a timing test, and a driving test.

In the cognition-response time, a traffic light was displayed on the monitor, and the colors (red, green, and yellow) were randomly presented. The subjects were instructed to continue pressing the accelerator when the light was not illuminated, to quickly remove their foot from the accelerator and step on the brake when the red light was illuminated, to recommence pressing on the accelerator when the green light was illuminated, and to remove their foot from the accelerator when the yellow light was illuminated. The red light was displayed a total of 20 times, and the test duration was approximately 7 minutes. The passage of time from when the red

Table 2 Measurements by simulator

Measurement	Group with brain lesions (n = 14)	Control group (n = 62)
Cognition-response time (sec)		
Mean value	0.94 ± 0.20 *	0.82 ± 0.11
Standard deviation	0.12 ± 0.06	0.09 ± 0.04
Predicted time (sec)	0.29 ± 0.57	0.33 ± 0.60
Rate of collision risk index (%) > 1	31.6 ± 29.3	35.0 ± 29.8

*: Group with brain lesions vs. Control group; t-test, $p < 0.05$
(Three patients were removed from the patient group and 3 from the control group, because they had no driver's license.)

light was turned on until the subject stepped on the brake was determined as the cognition-response time, the mean value was determined as an index of visual cognition and motor response, and variation (standard deviation) was determined as an unexpected delay in the cognition-response time that could potentially lead to an accident[9].

In the timing test, a car that was parked on the upper left of the monitor began to travel toward the right in response to the operation by the subjects and then hid behind a building once, so the subjects were instructed to predict the timing of the car appearing again and to press Button A. This was repeated 10 times, and the mean of the difference between the timing at which the button was pressed and the actual timing at which the car appears from behind the building was determined as the predicted time, which was an index of a tendency to act before the proper time[9].

In the driving test, the subjects was instructed to follow a car in front of them displayed on the monitor by operating the steering wheel, accelerator, and brake without causing a collision or deviating from the road while paying an attention to traffic lights and curves. The test duration was approximately Seven minutes, and the value obtained by dividing the stopping distance estimated from the result of the cognition-response time by the inter-vehicular distance while driving was determined as the collision risk index. When the collision risk index exceeded a level of 1, the risk of collisions increased[9], and therefore the rate of time in which this index exceeded 1 while driving was used for evaluation purposes.

The measurements of both groups were compared using a t-test. Regarding the group with brain lesions, correlations among the measurements and driving career or the results of neuropsychological tests (MMSE, WAIS-R, WMS-R, TMT, PASAT) were analyzed using the Pearson correlation coefficient. The values in which the P-value did not exceed 0.05 were determined to be significant.

Results

The mean value of the cognition-response time was significantly greater in the patient group than the control group (Table 2, t-test, $p<0.05$). However, the standard deviation of the cognition-response time and the predicted time and rate of collision risk index (> 1) showed no significant difference between the two groups.

The driving career and the measurements by simulator of the patient group are shown in Table 3. Three patients had no driver's license at the time and 14 had; Eight patients had less than 100 km/month of recent driving distance and 6 had 100 km/month or more than 100 km/month. The measurements of patients without a driver's license showed a tendency to increase in the standard deviation of the cognition-response time and the rate of collision risk index (> 1), and decrease in the predicted time, but the differences were not statistically analyzed because of a limited number of the patients. With regard to the driving distance (less than 100 km/month or at least 100 km/month), the mean value and standard deviation of the cognition-response time were significantly greater in the patients with less than 100 km ($p<0.05$, t-test).

With regard to correlations between the measurements by the simulator and the neuropsychological test, the standard deviation of the cognition-response time had significant correlations with the verbal IQ ($r=-0.729$) and full IQ ($r=-0.740$) of WAIS-R, and the predicted time demonstrated significant correlations with the verbal IQ of WAIS-R ($r=0.296$), verbal memory index ($r=0.695$) and general memory index ($r=0.716$) of

Table 3 Driving career and measurements by simulator

Driving career		Cognition-response time (sec)		Predicted time (sec)	Rate of collision risk index > 1 (%)
		Mean	Standard deviation		
Driver's license	Without (n = 3)	0.93 ± 0.11	0.21 ± 0.11	− 0.14 ± 0.43	57.4 ± 22.4
	With (n = 14)	0.94 ± 0.20	0.12 ± 0.06	0.29 ± 0.57	36.1 ± 29.3
Distance	Less than 100 km/month (n = 8)	0.97 ± 0.27 *	0.14 ± 0.07 *	0.31 ± 0.58	31.6 ± 29.3
	At least 100 km/month (n = 6)	0.91 ± 0.03	0.09 ± 0.02	0.25 ± 0.60	25.6 ± 27.1

*: Less than 100 km/month vs. at least 100 km/month; t-test, $p < 0.05$

WMS-R, and PASAT ($r = 0.713$) (Pearson's correlation coefficient, $p < 0.05$).

Discussion

The present study has some unsolved issues, because the causes of brain lesions in the group with brain lesions varied, and the number of cases was low, the age composition of the group of patients with brain lesions and the group of control subjects were different, and the history of traffic accidents could not be analyzed. However, evaluating (and studying) the driving characteristics of patients with brain lesions before using the present simulator for future clinical applications would be within the accepted range. Moreover, the control group was biased toward a younger generation, but it is believed that this cannot be avoided in a preliminary study, because we are planning this test for use in giving an advice mainly to patients with traumatic brain injuries from 20 to 30 years old, who intended to recommence car driving. It may be difficult to set standard values with middle-aged and elderly patients.

1. Mean value of cognition-response time

Hashimoto, et al.[8] reported the reaction time of patients with a cerebrovascular disease to be later than the standard value of healthy subjects of a similar age, and it moreover correlated with the evaluation results of street driving on a driving school course. The results of our study revealed that the cognition-response time of the group with brain lesions was later than the control group, and the cognition-response time of the patients who did not drive more than 100 km/month after the accident was delayed. However, it is not clear whether patients with the late cognition-response time refrained from driving or whether the late cognition-response time did not improve after the traffic accident because they have few opportunities to drive. One may speculate that motor paralysis was one of the major causes of the delay in the cognition-response time. Although Six patients with hemiplegia were included, the degree of hemiplegia was mild and no patients with hemiplegia had a cognition-response time that was delayed by more than 1 standard deviation from the mean value. Therefore, motor paralysis was not the major cause of the delay.

In association with the neuropsychological test, Mazer, et al.[5] pointed out a correlation between the results of street driving tests and TMT B, but according to the results of our study, significant correlations were not observed.

2. Standard deviation of cognition-response time

The group with brain lesions considerably varied regarding the cognition-response time in comparison to the control group, and the patients with less driving distance for 1 month showed the significantly greater standard deviation of the cognition-response time. Matsunaga has described that one of the causes of accidents is an unexpected delay in the cognition-response time because of the prolonged information-processing and cognition-response time induced by a decrease in arousal level and visual functions while driving[9]. It is necessary to consider causes depending on age, but it is expected that patients with brain lesions tend to demonstrate an unstable cognition-response time.

According to the neuropsychological tests, patients with brain lesions whose cognition-response time largely varied tend to be low in verbal IQ and full IQ, and it is necessary to pay an attention to the fact that their cognition-response is unstable at least when the IQ is low.

3. Predicted time

The predicted time of the group with brain lesions was shorter than the control group, but no significant difference was observed. This timing test is widely used at common driving schools as a speed anticipation reaction test[10][11], and it evaluates the sense of speed and feeling of haste. Many people who have had traffic accidents tend to hurry, and their predicted time becomes shorter and is displaced to a negative value[9]. In this investigation, BADS was not implemented for patients with a cerebrovascular disease who had no executive dysfunction. A correlation between the measurements by the simulator and scores according to BADS was not analyzed, but such measurements may decrease or become negative with disinhibition or impulsivity due to a frontal lobe lesion.

According to the neuropsychological tests, the patients showed obvious negative correlations between the tendency to hurry and the verbal memory index, general memory index, or PASAT, and therefore patients with either memory disturbance or inattention may therefore have an inferior ability for predicting the speed of cars.

4. Collision risk index

A higher rate of a collision risk index exceeding 1 increases the possibility of causing collisions more frequently, but the group with brain lesions showed a nearly equal level to that of the control group, and no patients with brain lesions who showed a significantly dangerous driving ability were found in this study. However, in the patients with brain lesions, the rate of the collision risk index exceeding 1 was higher in patients who rarely drove after their accident, so it is necessary to pay sufficient attention to their recommencement of driving and their safety while driving.

The present study is a preliminary study which did not incorporate a simultaneous street driving test. The results should not be generalized to all patients with brain lesions, and moreover, the recommencement of driving cannot be determined based on these results alone. However, it is necessary to understand that the response time of patients with brain lesions is delayed and varies considerably, the standard deviation correlates with the IQ, and the predicted time correlates with memory and PASAT. Therefore, these results may provide important informations when giving an advice to patients with higher brain dysfunction on car driving. It is required to continue to perform such studies after increasing the number of patients with traumatic brain injury, while we continue to improve the software program corresponding to the features of higher brain dysfunctions, and also adding the results of street driving tests in the future.

References

1) Hachisuka K: Higher brain dysfunction and car driving. Japanese Journal of Cognitive Neuroscience 9: 269—273, 2007.
2) Fox GK, Bowden SC, Smith DS: On-road assessment of driving competence after brain impairment: review of current practice and recommendations for a standardized examination. Arch Phys Med Rehabil 79: 1288—1296, 1998.
3) Tamietto M, Torrini G, Adenzato M, et al: To drive or not to drive (after TBI)? A review of the literature and its implications for rehabilitation and future research. NeuroRehabilitation 21: 81—92, 2006.
4) Patomella AH, Tham K, Kottorp A: P-drive: assessment of driving performance after stroke. J Rehabil Med 38: 273—279, 2006.
5) Mazer BL, Korner-Bitensky NA, Sofer S: Predicting ability to drive after stroke. Arch Phys Med Rehabil 79: 743—750, 1998.
6) Radford KA, Lincoln NB: Concurrent validity of the stroke drivers screening assessment. Arch Phys Med Rehabil 85: 324—328, 2004.
7) Tsuchishima M, Matsuhara M: Physical impairments and motor life—previous transitions and remaining issues. The Japanese Journal of Occupational Therapy Research 23: 414—419, 2004.
8) Hashimoto K, Ohashi M, Onishi M, et al: Car driving by patients with cerebrovascular damage—Medical issues and indicators of permission to drive. OT journal 36: 8—14, 2002.
9) Matsunaga K, editor: Human science of prevention of traffic accidents (Version 2). Kyoto, Nakanishiya Shuppan, 2006.
10) Saeki S, Ueda M, Hachisuka K, et al: Technical assessment for recommencing car driving for working people who have suffered a cerebrovascular disease. Occupational Health Journal 25: 18—21, 2002.
11) Maeda M, Kubota T, Inaba T, et al: Issues of car driving in patients with higher brain lesions. Sogo Rehabilitation 22: 127—132, 1994.

Reprint request:
Yasufumi Matsuda
Department of Rehabilitation Medicine, University of Occupational and Environmental Health Japan, 1-1, Iseigaoka, Yahatanishi-ku, Kitakyushu, Fukuoka Prefecture, 807-8555, Japan

別刷請求先 〒807−8555 北九州市八幡西区医生ヶ丘1−1
産業医科大学リハビリテーション医学講座
松田康父美

脳障害者の簡易自動車運転シミュレーションとその特性

松田康父美，加藤 徳明，岡崎 哲也
佐伯 覚，蜂須賀研二
産業医科大学リハビリテーション医学講座

—キーワード—
高次脳機能障害，自動車運転，シミュレーター

高次脳機能障害者の多くは社会復帰に際し自動車運転を希望するが，就業年齢にある場合はその傾向が特に強い．自動車運転再開の助言をするには運転に関する能力を適切に評価する必要があるが，現在，施設内でも簡単に実施できる標準化された検査はない．今回，簡易自動車運転シミュレーターを用いて認知・反応時間，予測時間，衝突危険指数を測定し，脳障害者17名（43.3±15.3歳）と健常者65名（23.6±1.6歳）の自動車運転特性を評価した．併せて運転経歴や神経心理テストとの関連を検討し，高次脳機能障害者の自動車運転助言に関する予備的研究を行った．

認知・反応時間の平均値は脳障害群が健常群よりも有意に大きく，さらに脳障害群のうち運転距離の少ない者では平均値と標準偏差が大きかった（t検定，$p<0.05$）．また，認知・反応時間の標準偏差とはWAIS-R言語性IQ・全IQが有意な負の相関（$p<0.05$，Pearson相関係数）があり，予測時間とはWAIS-R言語性IQ，WMS-R言語・一般的記憶指標点，PASATが有意な正の相関を示した（$p<0.05$，Pearson相関係数）．特に運転する機会が少ない脳障害者では，認知・反応時間が延長しばらつきが大きくなるという運転特性が明らかとなった．さらにIQが低い場合は認知・反応が不安定となり，記憶障害や注意障害がある場合は速度予測が劣り急ぎ傾向となった．

（日職災医誌，56：102—107，2008）