doi: 10.2490/prm.20210040 Progress in Rehabilitation Medicine 2021; Vol. 6, 20210040

ORIGINAL ARTICLE

Foundational Study on the Simple Detection of Impairment Resulting in Dangerous Driving in Patients with Higher Brain Dysfunction

Takashi Hiraoka, MD, PhD [a,b,c] Hiromichi Metani, MD, PhD [a,c] Masashi Yasunaga, MD [a,c]
Taketo Yoine, PhD [b,c] Masami Yagi, BSc [c] Sayako Yamamoto, MD, PhD [a,c] Nobuyuki Arai, MD, PhD [a,c]
Akio Tsubahara, MD, PhD [b] and Kozo Hanayama, MD, PhD [a,c]

Objectives: We performed a survey of medical records to reveal the cognitive deficits behind dangerous driving in patients with higher brain dysfunction. **Methods:** Thirty-four patients with higher brain dysfunction were included in this study. Patients' basic characteristics, neuropsychological test results, scores on two types of driving aptitude tests, and accident/near miss data from a driving simulator were extracted from medical records. We conducted χ^2 tests for independence between comprehensive driving aptitude scores and "traffic accidents" / "being prohibited from driving as defined by the number of traffic accidents and near misses." Backward logistic regression analysis was carried out to assess correlations of "traffic accidents" and "being prohibited from driving as defined by the number of traffic accidents and near misses" with neuropsychological test scores. **Results:** No significant correlation was observed between the comprehensive driving aptitude score and "traffic accidents" / "being prohibited from driving as defined by the number of traffic accidents and near misses." The score on the Raven's Colored Progressive Matrices test was the only factor identified as a significant predictor of "being prohibited from driving as defined by the number of traffic accidents and near misses." **Conclusions:** The results of this study suggest that it is important to focus on the decline in problem-solving ability as a predictor of "being prohibited from driving as defined by the number of traffic accidents and near misses."

Key Words: driving aptitude tests; driving simulator; higher brain dysfunction; Raven's Colored Progressive Matrices

INTRODUCTION

Maintaining certain levels of cognition, vision, motor function, and sensation is essential for safe driving.[1–3] In recent years, dangerous driving caused by reduced cognitive function in drivers has become a major problem in Japanese society.[4,5] Extensive research from the perspective of cognitive function is being conducted on this matter.[6–18] All dementia subtypes are considered to be typical causes of dangerous driving resulting from a decline in cognitive function; however, higher brain dysfunction has also been suggested to cause dangerous driving. "Higher brain dysfunction" is a medical term meaning "disorders involving a wide range of brain functions that require advanced, complex, and abstract processing" but it also has a narrower meaning as an administrative term defined by the Ministry of Health, Labour, and Welfare of Japan.[19] As a diagnostic term exclusively used by the government of Japan, "higher brain dysfunction" (in the narrow meaning), which is the subject of the current research, is defined by the Ministry

Received: March 30, 2021, Accepted: September 29, 2021, Published online: October 23, 2021
[a] Department of Rehabilitation Medicine, Kawasaki Medical School, Okayama, Japan
[b] Faculty of Rehabilitation, Kawasaki University of Medical Welfare, Okayama, Japan
[c] Department of Rehabilitation Medicine, Kawasaki Medical School Hospital, Okayama, Japan
Correspondence: Takashi Hiraoka, MD, PhD, Department of Rehabilitation Medicine, Kawasaki Medical School, 577 Matsushima, Kurashiki, Okayama 701-0192, Japan, Email: hiraoka@med.kawasaki-m.ac.jp

of Health, Labour and Welfare as "having limited everyday and societal activities due to cognitive impairment resulting from organic pathology in the brain."[20] Despite being in an unsafe cognitive state, some patients wish to resume driving or have already done so as a result of poor self-awareness.[18] Consequently, to maintain public safety, it is imperative to develop a system adapted to the medical setting for screening such dangerous drivers and to officially recommend that they no longer drive. Such a system will require the formulation of objective standards for determining the fitness to drive. Fitness-to-drive standards must provide accurate discrimination and be applicable to medical facilities with limited personnel, time, and financial resources, such that tests can be implemented quickly and easily. In other words, fitness-to-drive standards must meet the basic conditions for any screening test.

Standards for driving permission in the real world should emphasize whether the driver in question has a higher chance of causing an accident than a driver with normal levels of cognition. However, this is not easy to determine, and there is presently no consensus on the standards for making such a decision. In fact, assessing on the road whether a driver will cause an accident is difficult both ethically and practically from the point of view of protecting public safety. Therefore, using a driving simulator (DS) is considered to be a more realistic alternative to on-road assessment.[21] Accordingly, off-road evaluation, which combines both a series of neuropsychological tests[7,22] and a DS[13,18,21,23] is presently considered the optimal approach.[24] However, many clinical settings are not equipped with a DS. Therefore, in the current study, we investigated whether "traffic accidents" (discriminating healthy drivers) and "being prohibited from driving" (discriminating individuals who should not be permitted to drive) could be predicted from the results of brief and simple neuropsychological tests that would obviate the need for any special training in individuals with higher brain dysfunction. We also explored whether application of this approach could serve as foundational research for developing a test capable of screening fitness to drive without the need for a DS. Because intact cognitive function is required for safe driving, we hypothesized that frontal lobe functions, including attention, executive function, and general intellectual function, are important. The following assessments were performed after setting the items to be evaluated.

MATERIALS AND METHODS

Materials

The medical records were surveyed of 96 outpatients who had been referred to the Department of Rehabilitation Medicine at Kawasaki Medical School Hospital between April 1, 2014, and May 31, 2016, to assess their ability to drive. All patients were independent in their activities of daily living. Data for patients satisfying the following criteria were used for analysis: (1) having a valid Japanese driver's license (n=96); (2) diagnosed with higher brain dysfunction according to the diagnostic criteria of the Ministry of Health, Labour, and Welfare (n=96); (3) having the visual acuity and kinesthetic function necessary for driving (n=96); (4) having no severe unilateral spatial agnosia or aphasia (n=94); (5) having no history of dementia (n=96); (6) able to understand explanations of the Safety Navi test (SN) and able to complete the SN city course driving evaluation (DS mode) without experiencing simulator sickness (n=82) (14 patients were unable to complete the SN due to simulator sickness); (7) all of the following neuropsychological tests must have been performed without missing values (n=34): Trail Making Test A (TMT-A) (n=64), Trail Making Test B (TMT-B) (n=59), Raven's Colored Progressive Matrices (RCPM) (n=42), Mini-Mental State Examination (MMSE) (n=61), and the Metropolitan Police Department Driving Aptitude Test (CRT) (n=66); (8) all evaluations completed within 1 month after the start of testing (n=96). Data regarding 34 patients that were confirmed by a physiatrist to satisfy the abovementioned conditions (26 men/6 women; mean age, 58±14 years; range, 23–82 years old) were included in the analyses. Higher brain dysfunction in these 34 patients was caused by cerebrovascular disease (cerebral infarction/cerebral hemorrhage or non-traumatic subarachnoid hemorrhage; n=23), traumatic brain injury (cerebral contusion, diffuse axonal injury, traumatic subarachnoid hemorrhage, or acute subdural or epidural hemorrhage; n=10), or other causes such as encephalitis or hypoxic encephalopathy (n=1). At least 3 months had passed since the onset or injury in all cases. **Table 1** gives an outline of patient data.

Summary of Tests Used for Analyses

Neuropsychological Tests

TMT-A and TMT-B primarily assess visual search ability and selective attention function.[25] Part A involves connecting numbers in order with a line; part B involves connective alternating numbers and letters in order with a line. Part B, therefore, also assesses alternating attention. The time

Table 1. Demographics and test results of the 34 participants

		Anderson-Darling test (P value)
Age (years)	58±14; 23–82	0.435
Sex (male/female)	29/5	—
Diagnosis (cerebrovascular disease/TBI/other)	23/10/1	—
TMT-A	131±58; 55–378	0.0004
TMT-B	216±104; 86–598	0.0020
MMSE	27±4; 12–30	<0.0001
RCPM	28±6; 9–36	0.0360
Participants with each comprehensive CRT score: 1/2/3/4/5 points	4/11/7/7/5	-
Participants with each comprehensive SN score: 1/2/3/4/5 points	0/5/17/12/0	-
Accident in SN DS mode (yes/no)	30/4	-
Prohibited from driving in SN DS mode (yes/no)	13/21	-
Number of accidents in SN DS mode	3.3±2.7; 0–11	0.0376

Data are the number of subjects or mean±SD and range.
TBI, traumatic brain injury; TMT, Trail Making Test; MMSE, Mini-Mental State Examination; RCPM, Raven's Colored Progressive Matrices; SN, Safety Navi test; DS, driving simulator; CRT, Metropolitan Police Department Driving Aptitude Test.

Table 2. Average time taken for the TMT-A and TMT-B for different age groups as measured by Toyokura et al. 1996[29]

Age range (years)	n	TMT-A		TMT-B	
		Mean±SD (s)	Significance test	Mean±SD	Significance test
20–29	91	66.9±15.4	NS (20–29 vs 30–39)	83.9±23.7	NS (20–29 vs 30–39)
30–39	58	70.9±18.5	NS (30–39 vs 40–49)	90.1±25.3	
40–49	48	87.2±27.9		121.2±48.6	NS (40–49 vs 50–59)
50–59	45	109.3±35.6		150.2±51.3	
60–69	41	157.6±65.8		216.2±84.7	

NS, not significant.

required for the patient to complete each task and the difference between the times for the two tasks were assessed. A previous study reported that patients with frontal lobe damage require more time for part B, which indicates a clear decline in the ability to alternate attention.[26] Two variants of the TMT exist, one with a vertical layout, which is part of the Halstead-Reitan Battery, and one with a horizontal layout, which was created by Kashima et al.[27] More time is required to complete the horizontal layout TMT than the vertical layout TMT.[28] The standard time required by different age groups to complete the horizontal layout TMT is shown in **Table 2**.[29]

RCPM is used globally as an intelligence test in cases of dementia.[30] RCPM is not answered verbally and can therefore be used in patients with aphasia. RCPM is a puzzle-based test comprising 36 questions that are not influenced by the patients' cultural background. Examinees are instructed to select the one suitable pattern (from a choice of six) that corresponds to the missing pattern from a given sequence. A score of 24 points or less indicates reduced intelligence. With a completion time of 10–15 min, RCPM can be implemented in a relatively short period.

The MMSE comprises 11 questions and has a maximum score of 30 points; this test encompasses areas such as orientation, memory, calculation, linguistic ability, and graphic ability.[31] The MMSE is widely used to diagnose dementia; the cutoff value is 24 points.

Driving Aptitude Tests – Driving Simulator Used in Japan

The CRT measures a driver's aptitude.[32,33] Examinees follow directions displayed on a television screen and operate a steering wheel, accelerator, and brake. Individual reaction speed, accuracy, inconsistency in reaction, impatience, carelessness, distribution of attention, ability to disperse concentration, bad habits in operating the steering wheel, and balance are assessed by a computer. The results are compared with those of age-matched healthy individuals and presented as a comprehensive assessment in the form of a five-point scale: 1, inferior; 2, slightly inferior; 3, appropriate; 4, slightly excellent; and 5, excellent.

The SN test has features similar to those of the CRT, and the results are provided on a system-generated five-step scale normalized by age range. The SN value indicates driving aptitude. The SN involves a comprehensive set of driving aptitude scenarios with equipment that mimics the functioning of a vehicle. As shown in **Fig. 1A**, it can simulate driving conditions similar to those of a real car.[34] Examinees drive the simulator, which mimics a city environment, as displayed in **Fig. 1B**. The machine is also equipped with a comprehensive experience tutorial mode (DS mode), which, among other factors, assesses the driving speed, the number of near misses/accidents, and the number of ignored signals/signs while the subjects drive the course.

METHODS

The research design was a non-interventional, non-invasive, retrospective survey of medical records. Patient attributes (age, sex, and pathology), neuropsychological test results (TMT-A, TMT-B, RCPM, and MMSE), CRT comprehensive driving aptitude score (five levels), SN comprehensive driving aptitude score (five levels), and dangerous driving (traffic accidents/near misses) information from the SN (DS mode) were extracted from the medical records of the patients. Because cognitive function linked to frontal lobe function is considered important for judging whether a person is able to drive safely, analyses were performed using data from the CRT, the SN, and neuropsychological tests (horizontal layout TMT-A/B, RCPM, and MMSE). This study was conducted with prior approval from the Ethics Review Committee of Kawasaki Medical School (Approval No. 3893) and was supported by the Kawasaki Medical and Welfare Research Fund. Because this was a retrospective study and written informed consent was not applicable, the opportunity to refuse participation in the study was guaranteed through opt out.

Statistical Analyses

JMP (version 16) statistical software (SAS Institute, Cary, NC, USA) was used for statistical analyses.

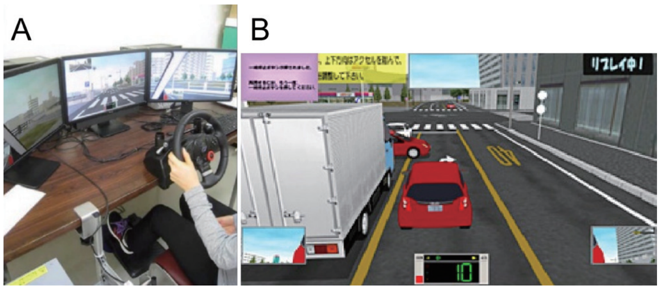

Fig. 1. The Safety Navi (SN) test. The SN testing equipment (A) and city street driving (DS mode) replay screen (B) used to simulate driving.

Analysis 1: Does the Comprehensive Driving Aptitude Score on a Driving Aptitude Test Reflect the Occurrence of Dangerous Driving (Traffic Accidents/Near Misses)?

The comprehensive driving aptitude score calculated by CRT/SN is an objective measure based on a five-point numerical scale and it may be suitable as a simple indicator for fitness to drive for medical professionals unaccustomed to making such decisions; however, evidence for this supposition is lacking. Therefore, we examined here whether it is possible to predict (a) "traffic accidents (yes/no)" and (b) "being prohibited from driving (yes/no)" using a comprehensive driving aptitude score. We conducted χ^2 tests to determine whether there was independence between the comprehensive aptitude test score and having a "traffic accident (yes/no)" or "being prohibited from driving (yes/no)". "Being prohibited from driving" was defined as having caused five or more accidents (multi-accident drivers), more than five total near misses or accidents (would-be multi-accident drivers), or three or more accidents and no near misses (delayed-decision multi-accident drivers) during the DS. Discussions were held by a team consisting of two physiatrists, one occupational therapist, and one speech–language pathologist who were familiar with higher brain dysfunction and driving evaluation. The above criteria were formulated based on our empirical judgment.

Analysis 2: Predicting Traffic Accidents/Being Prohibited from Driving with Neuropsychological Tests

We attempted to predict (a) "traffic accidents (yes/no)" and (b) "being prohibited from driving (yes/no)" using neuropsychological tests. The assessment of "traffic accidents (yes/no)" and "being prohibited from driving (yes/no)" was based

Table 3. Contingency tables (2 × 5) for the Metropolitan Police Department Driving Aptitude Test (CRT) comprehensive driving aptitude score (n=34)

		[1] Accident +/–			[2] Prohibited from driving +/–		
		+	–	Sum	+	–	Sum
Driving aptitude by CRT	1	2	2	4	1	3	4
	2	10	1	11	5	6	11
	3	7	0	7	4	3	7
	4	6	1	7	2	5	7
	5	5	0	5	1	4	5
	Sum	30	4	34	13	21	34

[1] P=0.1184 using Pearson's correlation coefficient.
[2] P=0.6304 using Pearson's correlation coefficient.

Table 4. Contingency tables (2 × 3) for Safety Navi test (SN) comprehensive driving aptitude score (n=34)

		[1] Accident +/–			[2] Prohibited from driving +/–		
		+	–	Sum	+	–	Sum
Driving aptitude by SN	2	5	0	5	3	2	5
	3	15	2	17	7	10	17
	4	10	2	12	3	9	12
	Sum	30	4	34	13	21	34

[1] P=0.6236 using Pearson's correlation coefficient.
[2] P=0.3762 using Pearson's correlation coefficient.

on data obtained from a driving session in which patients used a DS.

(a) Predicting "traffic accidents (yes/no)" based on neuropsychological tests

We performed backward stepwise logistic regression analysis with "traffic accidents (yes/no)" as the target variable and neuropsychological test results and age as predictor variables.

(b) Predicting "being prohibited from driving (yes/no)" based on neuropsychological tests

We performed backward stepwise logistic regression analysis with "being prohibited from driving (yes/no)" as the target variable and neuropsychological test results and age as predictor variables. We used a receiver operating characteristic (ROC) curve analysis to determine accuracy.[12] Cutoff values were indicated as the area under the curve (AUC).

RESULTS

Analysis 1: Does the Comprehensive Driving Aptitude Score on a Driving Aptitude Test Reflect the Occurrence of Dangerous Driving?

Tables 3 and 4 show the χ^2 test results for the relationship between having a traffic accident or being prohibited from driving in the DS and the comprehensive driving aptitude score on CRT/SN using 5×2/3×2 contingency tables. In the DS mode of the SN, the number of subjects who met with driving accidents was 30 ([1]), and the number of subjects determined to be prohibited from driving was 13 ([2]). No significant correlation with dangerous driving was observed for the comprehensive driving aptitude score in any of the tests (CRT: [1] Pearson p=0.12, [2] Pearson p=0.63, n=34 [**Table 3**]; SN: [1] Pearson p=0.62, [2] Pearson p=0.38, n=34 [**Table 4**]).

Analysis 2: Predicting Traffic Accidents/Being Prohibited from Driving Using Neuropsychological Tests

Stepwise logistic regression with "traffic accidents (yes/no)" as the target variable and TMT-A/TMT-B/MMSE/RCPM/age as predictor variables did not reveal any significant factors. However, stepwise logistic regression with "being prohibited from driving (yes/no)" as the target variable and TMT-A/TMT-B/MMSE/RCPM/age as predictor variables revealed that RCPM alone was a significant factor (odds ratio: 0.695, 95% confidence interval: 0.526–0.919; **Table 5**). The model's goodness-of-fit was evaluated using ROC curve analysis, which demonstrated a cutoff value of 28

Table 5. Data summary of stepwise logistic regression with "being prohibited from driving (yes/no)" as the target variable and RCPM as the predictor variable (n=34)

Variable	Coefficient	Standard error	Wald χ^2	P value	Odds ratio	95% CI
Intercept	9.697	3.941	6.054	0.014	-	-
RCPM	–0.364	0.142	6.530	0.011	0.695	0.526–0.919

points and an AUC of 0.85. The original cutoff for dementia for the RCPM test is 24 points.[29)]

DISCUSSION

The current study suggests that the standards for driving permission for individuals with dysfunction of higher-order brain function should focus on whether the driver in question has a higher probability of causing a traffic accident than a driver with normal levels of cognition. A comprehensive driving aptitude score measured using a driving aptitude test may be suitable as a simple indicator of fitness to drive for medical professionals with limited experience in making such decisions. However, there are no studies investigating whether this is truly relevant as an indicator of the risk of causing a traffic accident. Therefore, in Analysis 1, we investigated whether the comprehensive driving aptitude score on a five-point scale measured using two different driving aptitude tests could predict the probability of causing a traffic accident and/or being prohibited from driving in the DS. However, no significant relationship was observed between causing an accident and/or being prohibited from driving in the DS and the comprehensive driving aptitude score measured by either test. In other words, these results demonstrate that predicting dangerous driving, including accidents using a comprehensive score, is challenging; consequently, using a simple aptitude score to determine fitness to drive is not recommended. The comprehensive driving aptitude score calculated for this analysis thoroughly reflects brain function, including motor skills, cognition, and emotions.[32)] While the aptitude score may be a useful standardized indicator of driving skills, calculating a score that comprehensively includes a multitude of non-cognitive elements may result in underestimating reduced cognitive function. Notably, having a high average score for the various functions required for driving will not prevent accidents. In reality, the risk of a traffic accident increases if even a single item drops below the cutoff value. Therefore, it is essential not to be misled by the comprehensive driving aptitude score; rather, it is pertinent to emphasize the appropriate interpretation and application of subscales underpinning this score when determining fitness for driving.

Our study also focused on the use of neuropsychological tests, which are widely used in the clinical setting and are quickly and easily administered, in an attempt to identify a test that can be used as a fast and easy indicator of fitness to drive in numerous clinical settings not equipped with a DS. No significant predictors of “traffic accidents (yes/no)” were found, but the RCPM was shown to be a useful test for predicting “being prohibited from driving (yes/no)”. The reason that no predictors of traffic accidents were found is that traffic accidents can occur even in healthy individuals, and it may have been difficult to detect them with a simple test such as the one used in this study.

Novel aspects of the present research include defining “being prohibited from driving” (i.e., individuals who should not be allowed to drive) with a focus on the number of traffic accidents in the DS, as well as the number of near misses immediately before potential accidents, in an attempt to determine whether an individual should be prohibited from driving based on simple neuropsychological tests. Moreover, RCPM, which was adopted to predict driving prohibition, has not to date reportedly been associated with driving availability, making this the first report of its kind. RCPM, which was identified as a predictor of “being prohibited from driving,” is generally considered to be a non-verbal intelligence test based on “spatial perception” and “analogical reasoning”.[35,36)] Because RCPM requires the ability to deductively reason the sequential relationships between figures, it is considered to reflect general intelligence, or the g factor,[37)] in the psychology of thinking.[38,39)] RCPM is recognized as a useful measure of intelligence in studies of children and healthy adults.[40)] While some have argued for cognitive models such as the computational cognitive model[41)] or the noncomputational cognitive model,[42)] RCPM has been discussed in terms of the individual cognitive reasoning processes that mediate problem solving, rather than overall intelligence. For example, Carpenter et al.[43)] identified that RCPM measures the “ability to induce abstract relations” and the “ability to dynamically manage a large set of problem-solving goals in working memory.” In this context, the current results can be interpreted as indicating that individuals prohibited from driving are unable to abstractly induce problems with their own driving, recognize these problems, and resolve their dangerous driving behaviors, resulting in repeated near misses or accidents. Furthermore, the unaccountable error (one of the error patterns in RCPM) is highly correlated with the intelligence quotient, which may reflect abstract reasoning/problem-solving ability.[44] Additionally, Gainotti et al. reported that an error similar to the unaccountable error is an indicator of the degree of dementia in patients in the examination of RCPM in Alzheimer's disease/cerebrovascular dementia.[45] That article suggested that the unaccountable error is not directly correlated with "visuospatial factors" alone, which indirectly suggests that "being banned from driving" in our current study is not simply caused by a decline in visual cognitive function. Because we could not analyze the patterns of undesired RCPM responses in this study, the aforementioned is only an inference and must be validated in future studies. Moreover, if the RCPM is significantly affected only by visual and spatial higher brain processing, we would expect patients with right hemisphere damage to perform worse than those with left hemisphere damage. However, there are reports that RCPM results are worse in subjects with left hemisphere damaged.[46,47] We suspected that this finding indirectly indicated that the RCPM test is not affected only by visual and spatial higher brain processing. Accordingly, we speculated that a decline in RCPM score might be an indicator of repeated dangerous driving caused by a decline in logical thinking ability as well as spatial cognition. However, in the current study, we did not examine the effects of left–right lesions. We would like to investigate this in a future study.

In this study, "being prohibited from driving" refers to a state in which a person cannot abstractly or comprehensively understand the dangers associated with driving and cannot link these dangers with the avoidance of dangerous driving, and that RCPM may be used as a simple detection method for this condition. It has become clear that cognitive dysfunction in many areas affects driving, and the usefulness of various neuropsychological tests has been verified, but the accuracy of predicting performance in actual vehicle evaluations, which is considered the gold standard, is generally limited to about 60–80%.[22,48–50] Consequently, although it is not possible to make accurate judgments on whether a person should be allowed to drive based exclusively on RCPM test results, we believe that we have identified an approach that could indicate, to some extent, whether it would be dangerous for someone to drive. Moreover, the proposed assessment is time efficient and can be performed with limited resources.

Several limitations of this study should be noted: (1) this study was a retrospective survey of medical charts, (2) there were many missing values and few data that could be used for analysis, (3) it remains unclear whether the accidents measured using the off-road DS reflect actual traffic accidents; and (4) although it was possible to exclude cases in which DS evaluation could not be completed because of unequivocal simulator sickness, it is unclear how many mild cases were included in these data. Nevertheless, the results provide useful information that will contribute to the development of future screening tests.

We list several issues for consideration as we move forward in our research. The Stroke Driver Screening Assessment (SDSA) is a battery of four established subtests used to predict the driving ability of stroke survivors, and if all four subtest scores are above the cutoff value, the accuracy of predicting whether a person can drive is greater than 80%.[51] Since the Japanese version (J-SDSA) has become available, it has been used frequently in clinical settings in Japan. However, because it was not included in this study, it will be necessary to include SDSA as a predictor variable in future research.

Simulator sickness is considered to arise from the difference in driving sensation between an actual vehicle and the simulator. Such differences largely result from visual issues (difference between actual vision and image) and movement problems (difference between actual vehicle acceleration and simulator acceleration) and may trigger unusual sensations. In recent years, visual problems have been resolved with advances in image-processing technology that use high-definition and high-speed computer graphics images with a full-view dome screen.[52] With regard to kinetic issues, attempts have been made to reduce discomfort by enlarging the size of the simulator and expanding the range of motion.[53] However, the SN used here lacked the abovementioned functions, and simulator sickness occurred; therefore, the fundamental capabilities of the SN may have been obscured. In the future, it will be necessary to introduce the latest driving simulator technology and to enhance prediction accuracy by increasing the sample size and utilizing a prospective research design. Additionally, collaboration with police stations and driving schools to investigate correlations with an evaluation of actual driving skills will be necessary. A follow-up study on the actual status of accidents caused when patients resume driving after medical investigations/interventions is also needed. When fully automated driving systems are implemented in the future, patients with higher brain dysfunction will be able to enjoy transportation by car unless they have very severe cognitive decline. However, the development of fully automated vehicles and related relevant infrastructure and laws is not expected in the near future. Until society reaches that point, an appropriate assessment of driving ability will be required.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available upon request.

ACKNOWLEDGMENTS

This work was supported by the Kawasaki University of Medical Welfare Scientific Research Fund, 2014. We would like to thank Ms. Miyako Hirano for data management.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

REFERENCES

1. Watanabe S: Returning to driving and rehabilitation medicine [in Japanese]. Jpn J Rehabil Med 2020;57:110–116. DOI:10.2490/jjrmc.57.110
2. Physician's Guide to Assessing and Counseling Older Drivers: 2nd ed. The American Medical Association. 2010. https://ami.group.uq.edu.au/files/155/physicians_guide_assessing_older_adult_drivers.pdf. Accessed 23 Nov 2019.
3. D'apolito AC, Leguiet JL, Enjalbert M, Lemoine F, Mazaux JM: Return to drive after non-evolutive brain damage: French recommendations. Ann Phys Rehabil Med 2017;60:263–269. DOI:10.1016/j.rehab.2017.04.001, PMID:28533085
4. Miller BL, Darby A, Benson DF, Cummings JL, Miller MH: Aggressive, socially disruptive and antisocial behaviour associated with fronto-temporal dementia. Br J Psychiatry 1997;170:150–155. DOI:10.1192/bjp.170.2.150, PMID:9093504
5. Love CM, Welsh RK, Knabb JJ, Scott ST, Brokaw DW: Working with cognitively impaired drivers: legal issues for mental health professionals to consider. J Safety Res 2008;39:535–545. DOI:10.1016/j.jsr.2008.09.001, PMID:19010127
6. Tan KM, O'Driscoll A, O'Neill D: Factors affecting return to driving post-stroke. Ir J Med Sci 2011;180:41–45. DOI:10.1007/s11845-010-0528-9, PMID:20665122
7. Coleman RD, Rapport LJ, Ergh TC, Hanks RA, Ricker JH, Millis SR: Predictors of driving outcome after traumatic brain injury. Arch Phys Med Rehabil 2002;83:1415–1422. DOI:10.1053/apmr.2002.35111, PMID:12370878
8. Rapport LJ, Bryer RC, Hanks RA: Driving and community integration after traumatic brain injury. Arch Phys Med Rehabil 2008;89:922–930. DOI:10.1016/j.apmr.2008.01.009, PMID:18452742
9. Korteling JE, Kaptein NA: Neuropsychological driving fitness tests for brain-damaged subjects. Arch Phys Med Rehabil 1996;77:138–146. DOI:10.1016/S0003-9993(96)90158-6, PMID:8607737
10. Perrier MJ, Korner-Bitensky N, Mayo NE: Patient factors associated with return to driving poststroke: findings from a multicenter cohort study. Arch Phys Med Rehabil 2010;91:868–873. DOI:10.1016/j.apmr.2010.03.009, PMID:20510976
11. Lundqvist A, Alinder J, Rönnberg J: Factors influencing driving 10 years after brain injury. Brain Inj 2008;22:295–304. DOI:10.1080/02699050801966133, PMID:18365843
12. Aslaksen PM, Ørbo M, Elvestad R, Schäfer C, Anke A: Prediction of on-road driving ability after traumatic brain injury and stroke. Eur J Neurol 2013;20:1227–1233. DOI:10.1111/ene.12172, PMID:23560568
13. de Simone V, Kaplan L, Patronas N, Wassermann EM, Grafman J: Driving abilities in frontotemporal dementia patients. Dement Geriatr Cogn Disord 2007;23:1–7. DOI:10.1159/000096317, PMID:17047327
14. Novack TA, Baños JH, Alderson AL, Schneider JJ, Weed W, Blankenship J, Salisbury D: UFOV performance and driving ability following traumatic brain injury. Brain Inj 2006;20:455–461. DOI:10.1080/02699050600664541, PMID:16716991
15. Smith-Arena L, Edelstein L, Rabadi MH: Predictors of a successful driver evaluation in stroke patients after discharge based on an acute rehabilitation hospital evaluation. Am J Phys Med Rehabil 2006;85:44–52. DOI:10.1097/01.phm.0000184157.19912.96, PMID:16357548

16. Elkinfrankston S, Lebowitz B, Kapust L, Hollis A, O'Connor M: The use of the Color Trails Test in the assessment of driver competence: preliminary report of a culture-fair instrument. Arch Clin Neuropsychol 2007;22:631–635. DOI:10.1016/j.acn.2007.04.004, PMID:17481851
17. Schultheis MT, Whipple EK: Driving after traumatic brain injury: evaluation and rehabilitation interventions. Curr Phys Med Rehabil Rep 2014;2:176–183. DOI:10.1007/s40141-014-0055-0, PMID:25436178
18. Hiraoka T, Hanayama K, Metani H, Seki S, Shimizu S, Sugiyama T, Yagi M, Yoine T, Tsubahara A: Investigation into the safety of driving by individuals with higher brain dysfunction. Kawasaki Med J 2015;41:71–81.
19. Hiraoka T: Interpretations and applications of the term "higher brain dysfunction. Jpn J Compr Rehabil Sci 2021;12:1–3.
20. National Rehabilitation Center for Persons with Disabilities. http://www.rehab.go.jp/application/files/3915/1668/9968/3_1_01_.pdf. Accessed 4 Mar 2021.
21. Blane A, Falkmer T, Lee HC, Dukic Willstrand T: Investigating cognitive ability and self-reported driving performance of post-stroke adults in a driving simulator. Top Stroke Rehabil 2018;25:44–53. DOI:10.1080/10749357.2017.1373929, PMID:29022422
22. Hargrave DD, Nupp JM, Erickson RJ: Two brief measures of executive function in the prediction of driving ability after acquired brain injury. Neuropsychol Rehabil 2012;22:489–500. DOI:10.1080/09602011.2012.662333, PMID:22360153
23. Imhoff S, Lavallière M, Teasdale N, Fait P: Driving assessment and rehabilitation using a driving simulator in individuals with traumatic brain injury: a scoping review. NeuroRehabilitation 2016;39:239–251. DOI:10.3233/NRE-161354, PMID:27372359
24. Stolwyk RJ, Charlton JL, Triggs TJ, Iansek R, Bradshaw JL: Neuropsychological function and driving ability in people with Parkinson's disease. J Clin Exp Neuropsychol 2006;28:898–913. DOI:10.1080/13803390591000909, PMID:16822731
25. Strauss E, Sherman EM, Spreen O: A Compendium of Neuropsychological Tests: Administration, Norms and Commentary. 3rd ed. Oxford University Press, New York, 2006.
26. Reitan RM, Wolfson D: The Halsted-Reitan Neuropsychological Test Battery. Neuropsychology Press, Tucson, 1985.
27. Kashima H, Handa T, Kato M: Disorders of attention due to frontal lobe lesion [in Japanese]. Shinkei Kenkyu No Shimpo 1986;30:847–858.
28. Takeda C, Nakashima K, Notoya M, Sunahara N: Differences between vertical and horizontal layout Trail Making Tests: a study based on a comparison of healthy young subjects. Jpn J Neuropsychol 2017;33:207–215.
29. Toyokura M, Tanaka H, Furukawa T: Normal aging effect on cognitive task performance of information-processing speed: analysis of paced auditory serial addition task and trail making test. Brain Sci Ment Dis 1996;7:401–409.
30. Raven JC: Colored Progressive Matrices Sets A, Ab, B. Psychologists Press, Oxford, 1947.
31. Folstein MF, Folstein SE, McHugh PR: "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–198. DOI:10.1016/0022-3956(75)90026-6, PMID:1202204
32. Matsunaga K: Human Science for Prevention of Road Accidents. Nakanishiya Publishing, Kyoto, 2002.
33. Otsuka H, Tsurutani K, Kainuma Y, Isobe J, Matsuura T, Yamaguchi T, Uchida C: Development of CRT driving aptitude test system. Reports of the National Research Institute of Police Science [in Japanese]. Res Traffic Saf Regul 1990;31:57–65.
34. Honda Motor Co: Ltd. https://www.honda.co.jp/safetyinfo/simulator/safetynavi/rehabilitation.html [in Japanese]. Accessed 4 March 2021.
35. Cronin-Golomb A: Abstract thought in aging and age-related neurological disease. In: Boller F, Grafman J, editors. Handbook of Neuropsychology. Vol. 4. Amsterdam: Elsevier; 1990. pp. 279–309.
36. Lezak MD: Concept formation and reasoning. In: Neuropsychological Assessment. 3rd ed. New York: Oxford University Press; 1995. pp. 602–649.
37. Spearman C: The Abilities of Man. New York: Macmillan; 1927.
38. Basso A, De Renzi E, Faglioni P, Scotti G, Spinnler H: Neuropsychological evidence for the existence of cerebral areas critical to the performance of intelligence tasks. Brain 1973;96:715–728. DOI:10.1093/brain/96.4.715, PMID:4773862
39. De Renzi E: Disorders of spatial thought. In: De Lenzi E, editor. Disorders of Space Exploration and Cognition. Chichester: John Wiley & Sons; 1982. pp. 172–196.

40. Llabre MM: Standard Progressive Matrices. In: Keyser DJ, Sweetland RC, editors. Test Critiques, Vol I. Kansas City, MO: Test Corporation of America; 1984. pp 26.
41. Schwartz E: Computational Neuroscience. Cambridge, MA, MIT Press, 1990.
42. Globus GG: Toward a noncomputational cognitive neuroscience. J Cogn Neurosci 1992;4:299–300. DOI:10.1162/jocn.1992.4.4.299, PMID:23968124
43. Carpenter PA, Just MA, Shell P: What one intelligence test measures: a theoretical account of the processing in the Raven Progressive Matrices Test. Psychol Rev 1990;97:404–431. DOI:10.1037/0033-295X.97.3.404, PMID:2381998
44. Mimura M, Kato M, Kashima H: Qualitative analysis of errors on Raven's Coloured Progressive Matrices [in Japanese]. Jpn J Neuropsychol 1997;13:29–37.
45. Gainotti G, Parlato V, Monteleone D, Carlomagno S: Neuropsychological markers of dementia on visual-spatial tasks: a comparison between Alzheimer's type and vascular forms of dementia. J Clin Exp Neuropsychol 1992;14:239–252. DOI:10.1080/01688639208402826, PMID:1572947
46. Arrigoni G, De Renzi E: Constructional apraxia and hemispheric locus of lesion. Cortex 1964;1:170–197. DOI:10.1016/S0010-9452(64)80020-4
47. Kertesz A, McCabe P: Intelligence and aphasia: performance of aphasics on Raven's coloured progressive matrices (RCPM). Brain Lang 1975;2:387–395. DOI:10.1016/S0093-934X(75)80079-4, PMID:1218375
48. Yamada K, Sasaki T, Kudo A, Sengoku Y: Relationships between neuropsychological tests and on-road driving assessment for stroke patients [in Japanese]. High Brain Funct Res 2013;33:270–275. DOI:10.2496/hbfr.33.270
49. Kato T, Kishimoto S, Inobe J: Driving ability-related neuropsychological test for patients with brain disorder: systematic review and meta-analysis [in Japanese]. Sogo Rehabil 2016;44:1087–1095.
50. Yamada K, Kato T, Sotokawa T, Fujita Y, Mimura M: Investigation of reference score of the Stroke Drivers' Screening Assessment Japanese Version (J-SDSA) [in Japanese]. High Brain Funct Res 2018;38:239–246. DOI:10.2496/hbfr.38.239
51. Kobayashi Y, Omokute Y, Mitsuyama A, Takaoka Y, Takama C, Watanabe Y: Predictors of track test performance in drivers with stroke. Turk Neurosurg 2017;27:530–536. PMID:27593824
52. Takakuwa Y, Awaya I, Goto M, Kubo T, Okada T, Okada K: Development of the driving simulator reducing simulator sickness [in Japanese]. Mitsubishi Jyuukou Gihou 2009;46:38–42.
53. Yonekawa T, Aga M, Kadowaki M, Nagiri S, Sakaguchi Y, Araki A: Development of driving simulator with high reality for town driving [in Japanese]. Jidousya Gijyutsukai Ronbunnsyuu 2008;39:29–34.