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Original Article

Relationship between Driving Skills and Cognitive Functions in Cerebrovascular Disease Patients and Short-Term Effects of Driving Training

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SUMMARY

Background: This study aimed to investigate the relationship between driving skills and cognitive function in patients with cerebrovascular disease and provide driving rehabilitation strategies based on actual vehicle driving training.
Methods: Participants included 25 patients with cerebrovascular disease who wished to resume driving. The Mini-Mental State Examination (MMSE), Frontal Assessment Battery, and Trail Making Test were administered to assess cognitive function. Driving rehabilitation consisted of two driving sessions and verbal instruction from the driving school instructor between the first and second driving sessions. All of these sessions took place on the same day. The evaluation of actual vehicle driving was based on quantified point reduction items. This evaluation method is the evaluation scale used in the skill test for obtaining a Japanese automobile license and is based on the Japanese National Police Agency.
Results: MMSE scores were extracted as a factor influencing actual vehicle driving performance. Furthermore, the MMSE scores were entered into a stepwise multiple regression model, which revealed that MMSE scores were an important predictor of actual vehicle driving performance. Driving rehabilitation resulted in improved actual vehicle driving performance. Moreover, the number of participants who passed the test increased from two to 11 ($p < 0.001$).
Conclusions: Driving rehabilitation was found to have some positive effects, such as an increase in the pass rate for actual vehicle driving. However, it is necessary to consider the possibility that this effect could be due to the repetition of two driving sessions conducted on the same day.

1. Introduction

Stroke is the primary cause of disability and vascular death worldwide.[1] Patients who have had a stroke may require rehabilitation to participate in social activities and return to work. Depending on their condition, these patients are known to face difficulty resuming daily and social activities,[2] and commonly experience a loss of social opportunities, relationship changes, and social isolation.[3] Evidence suggests that such patients who can continue to drive a car can continue to work, pursue hobbies, and engage in other important daily activities.[4] There are policies in many countries that require a physician's report and subsequent assessment prior to driving again.[5] More specifically, the physician issues a recommendation for resuming driving after referring to medical data, including neuropsychological examinations, brain imaging scans, and driving aptitude evaluations (actual road tests).[6] However, since the myriad of physical and cognitive impairments following a stroke may affect motor vehicle driving,[7] many patients face difficulty resuming driving after stroke.[8]

Approximately 35% of patients with stroke require driving-related rehabilitation before they can safely resume driving.[9] Furthermore, approximately 46% of patients who experience a stroke are unable to return to driving owing to residual visual or cognitive impairments.[10] Therefore, the importance of driving rehabilitation and establishing definitive criteria for propriety judgment in the reacquisition of driving among such patients is high.

Vision is the most important source of information in driving and many driving-related accidents are associated with visual impairment.[11,12] Visual functions related to driving include visual acuity, visual field, contrast, and many other factors.[13] In addition, driving is a complex task that involves not only visual function, but also a wide range of cognitive skills and multisensory perception.[14] For example, controlling a vehicle takes place in a visually cluttered environment and involves the simultaneous use of central and peripheral vision and the execution of primary and secondary tasks (both visual and non-visual).[13] However, patients with cerebrovascular disease may have a variety of impairments that may affect their ability to drive, including decreased visual field, visual scanning, attention, information processing speed, physical performance, and visuospatial skills.[15–20]

Post-stroke driving assessments usually emphasize visual and cognitive assessments more than physical function assessments.[21,22]

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According to previous reports on the relationship between post-stroke driving skills and cognitive function, the decline in executive function predicts poor driving outcomes and fitness to drive following a stroke.[9,23] Stroke survivors with impaired attention demonstrate worse on-road driving skills and are less likely to resume driving.[24,25] Driving mistakes due to cognitive impairment are major obstacles toward driving safely for patients with stroke;[26] therefore, continuous consideration is required in the future.

Post-stroke driving rehabilitation can be categorized into basic training consisting of perceptual, cognitive, physical, and/or visual skills, and driving-focused approaches such as driving simulators and on-road training.[27] Although there have been several reports of on-road training using actual vehicles in studies with older adults,[28,29] there have been few reports and no randomized controlled trials for patients who have experienced a stroke.[30] In addition, the results indicated no improvement in roadway driving assessments immediately or 6 months after intervention for either the driving simulator or the basic approach.[30] We conclude that there is insufficient evidence regarding rehabilitation for improving roadway driving ability after stroke, and further verification is necessary.

This study aimed to investigate the relationship between driving skills and cognitive function in patients with cerebrovascular disease and provide driving rehabilitation strategies based on actual vehicle driving training that support the resumption of driving, which is essential for health, well-being, social interaction, productivity, and quality of life.

2. Materials and methods

2.1. Participants

The enrolled participants (n = 25) were recruited from among patients who had visited the Saga University Hospital due to cerebrovascular disease (those who had experienced a cerebrovascular disease) and wanted to resume driving. The study was conducted in Saga Prefecture, Japan, from April 2020 to March 2022.

Participant selection was based on the dispensation of the attending physician in charge of the current study. Patients with dementia, severe cognitive impairment, or physical disability were excluded as these conditions were considered to interfere with driving ability at the time of diagnosis by the attending physician (Table 1).

2.2. Driving rehabilitation

The driving rehabilitation consisted of two actual vehicle driving sessions and verbal instructions given by a driving school instructor. Participants drove on a designated course at a driving school while following the instructions of the driving school instructor (first driving session). An interval of about 1 hour was provided after the first driving session. During the interval, participants received verbal instruction from the driving school instructor. The content of the verbal instruction was based on the results of the evaluation of the first driving session, in which participants were given advice regarding driving errors (e.g., steering, missing signs and stop lines, adjusting speed, etc.) that were different for each participant. A second actual vehicle driving session was performed after the end of the interval. The second driving session was the same as the first one at the driving school, where the students drove on the designated course while following the driving school instructor's instructions. After the second driving session, the driving school instructor gave feedback on the actual driving again to complete the entire process (Figure 1). The actual vehicle driving included multiple checkpoints (driving in a straight line, curves, cranks, signals and signs, temporary stops, railway crossing, how to start and stop, etc.). The time required for one actual vehicle driving session was approximately 30 minutes. Although the driving courses for the first and second driving sessions were on different routes, the checkpoints were the same (Figure 2).

Table 1
Participants' baseline characteristics (n = 25).

Variable	
Sex, n (%)	
Male	18 (72.0)
Female	7 (28.0)
Age, mean (SD)	55.6 (9.6)
Type of disease, n (%)	
Cerebral infarction	11 (44.0)
Cerebral hemorrhage	8 (32.0)
Subarachnoid hemorrhage	2 (8.0)
Cerebral contusion	2 (8.0)
Other	2 (8.0)
Neuropsychological tests, mean (SD)	
MMSE	27.6 (2.2)
FAB	15.0 (1.9)
TMT-A (seconds)	55.5 (29.7)
TMT-A (errors)	0.08 (0.2)
TMT-B (seconds)	133.7 (77.8)
TMT-B (errors)	0.52 (0.9)

MMSE: Mini-Mental State Examination; FAB: Frontal Assessment Battery; TMT: Trail Making Test.

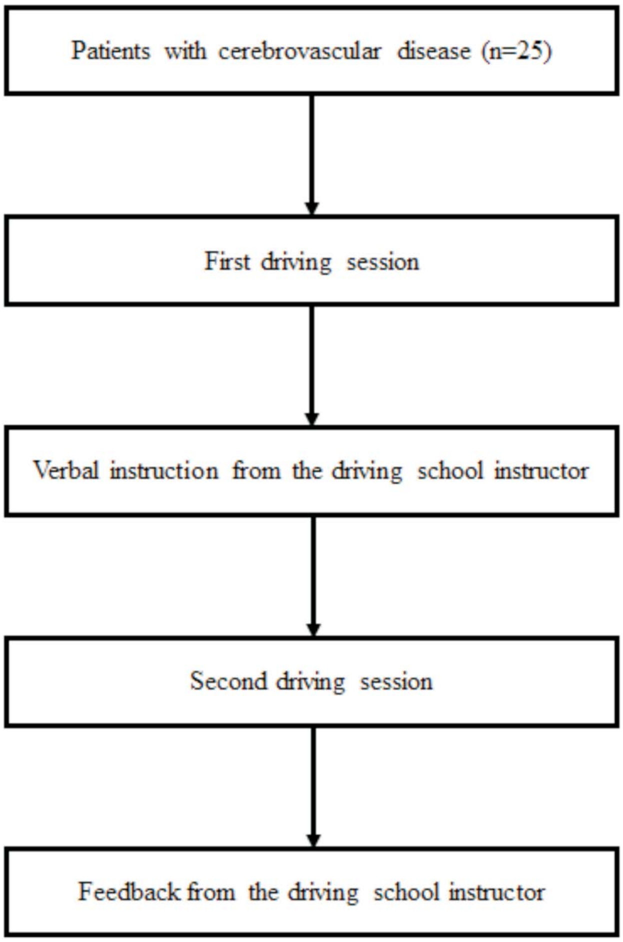

Figure 1. Driving rehabilitation protocols.

Figure 2. Driving school course.

2.3. Evaluation items

2.3.1. Evaluation of actual vehicle driving

The actual vehicle driving conducted as part of the driving rehabilitation program was evaluated by a driving school instructor who was certified as a skilled tester and rode in the passenger seat. All evaluations in the current study were conducted by the same driving school instructor. The evaluation method is based on quantified point deductions and the total points deduction increases when a participant makes an error corresponding to a point deduction item while driving. The points deductions were classified into 20, 10, and 5-point deductions. In addition to those point reduction items, there were also serious errors (test-discontinuation items) resulting in failure if they occurred even once (Supplementary Material).

Those with total points deduction of 30 points or less at the end of driving with no test-discontinuation items were considered to have passed the session. This evaluation method is the evaluation scale used in the skill test for obtaining a Japanese automobile license and is based on the Japanese National Police Agency. For actual vehicle driving, an automatic transmission vehicle equipped with an auxiliary brake for the passenger seat was used, and similar vehicles were provided to all participants.

2.3.2. Neuropsychological examinations

2.3.2.1. Mini-Mental State Examination

The Mini-Mental State Examination (MMSE) is the most widely used international neurological screening test, with a total possible score of 30 points. The test assesses multiple cognitive functions, including orientation, memory, attention, calculation, language, verbal command action, and figure copying.[31,32]

2.3.2.2. Frontal Assessment Battery

The Frontal Assessment Battery (FAB) can be performed relatively easily as a screening test for assessing frontal lobe dysfunction.[33] It consists of six test items classified into similarity, vocabulary flexibility, motor programming, interference instruction execution, behavior suppression, and forced grasp domains, with a total possible score of 18 points.

2.3.2.3. Trail Making Test

The Trail Making Test (TMT) is a screening test used as an index of visual scanning, writing speed, and executive function.[34,35] The TMT consists of two testing components classified as TMT-A and TMT-B subsections. The TMT-A task is to connect randomly arranged numbers from 1 to 25 as quickly as possible. TMT-B is similar to TMT-A; however, numbers and letters are arranged randomly, and it is necessary to switch between numbers and letters as soon as possible (1-A, 2-B, 3-C, etc.). For both TMT-A and TMT-B, we measured the time from the start of the test to the end of the test and the number of errors.

2.4. Statistical analyses

The analysis process involved several stages. First, the total reduction in points for the second driving session was used as the dependent variable. Age, sex, MMSE, FAB, TMT-A, and TMT-B (seconds, error) were used as independent variables in the univariate regression analysis. Moreover, the stepwise multiple regression analysis was conducted to investigate potential predictors of actual vehicle driving. Next, to clarify the effects of driving rehabilitation, the results of the first and second driving sessions were compared by the paired t-test. McNemar's test was used to compare the proportion of participants who passed or failed their first and second driving sessions. Third, to analyze the most important test-discontinuation items among the point reduction items in detail, the test-discontinuation items for all participants were aggregated from the results of the first and second driving sessions (multiple sessions were included as well). The significance level was set at 0.05. All p values < 5% were considered to indicate statistical significance. All statistical analyses were performed using IBM SPSS Statistics 25.

2.5. Ethical considerations

This study was approved by the Research Ethics Review Committee of Saga University School of Medicine and the Research Ethics Review Committee of the International University of Health and Welfare (Approval numbers: R3-23, 21-Ifh-068). All participants provided written informed consent prior to participation.

3. Results

3.1. Neuropsychological tests and actual vehicle driving performance

Univariate regression analysis was used to investigate neuropsychological tests related to actual vehicle driving performance. The results of the univariate regression analysis showed that MMSE scores had an effect on the actual vehicle driving performance (β = -0.471, p = 0.017) (Table 2).

The stepwise multiple regression analysis showed an association between age (β = 0.472, p < 0.004), sex (β = 0.591, p = 0.001), and MMSE (β = -0.542, p < 0.001), with a significant regression coefficient (R^2 = 0.606) (Table 3).

3.2. Comparative driving performance

We compared the results of the first and second driving sessions to verify the effects of driving rehabilitation. We found a statistically significant improvement in all evaluated items of the results for the second session compared with the first session (Table 4). In terms of the pass rate, only two participants passed the first session; in contrast, 11 participants passed the second session (p < 0.001) (Table 5).

3.3. Test-discontinuation items

The total types of errors counted from the first and second sessions of the test-discontinuation item was six. The number of errors for test-discontinuation items was 28 in the first session and 15 in the second session. The error items were classified into three categories according to the type of error: Operation-related errors (Off-wheel [large] and Contact [large]), Non-stop-related errors (Violation of temporary stop and Railway crossing non-stop), and other errors (Right-hand traffic and Progress obstruction) (Table 6). The number of errors decreased from the first to the second sessions, with a particularly large decrease observed in stop errors (Violation of temporary stop) (First session: nine, Second session: two).

4. Discussion

This study investigated the relationship between driving skills and cognitive function in patients with cerebrovascular disease and provided driving rehabilitation at a driving school to gather new evidence for a driving rehabilitation program.

The results of the FAB, TMT-A, and TMT-B (seconds, errors) analyses had no effect on actual vehicle driving. However, MMSE scores were shown to affect actual vehicle driving. Furthermore, the MMSE scores were entered into a stepwise multiple regression model, which revealed that MMSE scores was an important predictor of actual vehicle driving performance.

A meta-analysis of predictors of patients returning to driving after a cerebrovascular disease reported in 2023 found that MMSE

Table 2
Univariate regression analysis with actual vehicle driving evaluation as the dependent variable (n = 25).

Independent variable	B	SE	β	p
Age	0.885	0.463	0.37	0.069
Sex	15.0	10.003	0.298	0.147
MMSE	-4.868	1.899	-0.471	0.017
FAB	-2.923	2.449	-0.242	0.245
TMT-A (seconds)	-0.26	0.161	-0.33	0.875
TMT-A (errors)	-15.435	17.045	-0.186	0.375
TMT-B (seconds)	0.059	0.06	0.198	0.342
TMT-B (errors)	6.538	4.8	0.273	0.186

MMSE: Mini-Mental State Examination; FAB: Frontal Assessment Battery; TMT: Trail Making Test; B: unstandardized estimate; SE: standard error; β: standardized estimate, p: p-value.

Table 3
Multiple regression analysis with actual vehicle driving evaluation as the dependent variable (n = 25).

Independent variable	B	SE	β	p	VIF	R^2
Age	1.129	0.348	0.472	0.004	1.131	
Sex	29.707	7.459	0.591	0.001	1.174	0.606
MMSE	-5.592	1.469	-0.542	0.001	1.079	

MMSE: Mini-Mental State Examination; B: unstandardized estimate; SE: standard error; β: standardized estimate; p: p-value; VIF: Varience Inflation Factors; R^2: coefficient of determination.

Table 4
First and second results of actual vehicle driving (overall) (n = 25).

	First†	Second†	p-value*	Effect size (d)
Overall				
Test-discontinuation items	1.12 ± 1.7	0.56 ± 1.0	0.013	0.4
Total points deduction	66.6 ± 32.6	39.2 ± 23.0	< 0.001	0.97
20 point deductions	7.2 ± 14.0	1.6 ± 5.5	0.032	0.53
10 point deductions	40.0 ± 18.4	24.4 ± 16.8	< 0.001	0.89
5 point deductions	19.4 ± 12.1	13.2 ± 7.6	0.006	0.61

Paired t-test.
* p value < 0.05 represents significant differences between 1st and 2nd.
† Mean ± SD.
Effect size: The standard of effect size was small (0.20), medium (0.50), and large (0.80).

Table 5
First and second results of actual vehicle driving (Pass/Fail) n = 25.

First	Second (Pass/Fail)		
(Pass/Fail)	Pass	Fail	p-value*
Pass	2 (1.4)	0 (-1.4)	< 0.001
Fail	11 (-1.4)	12 (1.4)	

McNemar test.
* p value < 0.05 represents significant differences between 1st and 2nd.
Adjusted standardized residuals appear in parentheses.

Table 6
Classification of the test-discontinuation items.

Test-discontinuation items				
Classification	First item	Number (%)	Second item	Number (%)
Operation-related errors	Off-wheel (large)	11 (39.3)	Off-wheel (large)	9 (60.0)
	Contact (large)	5 (17.9)	Contact (large)	3 (20.0)
Non-stop-related errors	Violation of temporary stop	9 (32.1)	Violation of temporary stop	2 (13.3)
	Railway crossing non-stop	0 (0.0)	Railway crossing non-stop	1 (6.7)
Other errors	Right-hand traffic	2 (7.1)	Right-hand traffic	0 (0.0)
	Progress obstruction	1 (3.6)	Progress obstruction	0 (0.0)
Total		28 (100)		15 (100)

Numbers of errors are counted in duplicates.

scores were an important predictor of resumption of driving.[36] Furthermore, the driving rehabilitation conducted in this study consisted of two actual vehicle driving sessions and verbal instruction from a driving school instructor. This requires that the verbal instruction of the driving school instructor be immediately utilized in second driving sessions. We think that participants with relatively high cognitive function were able to understand the verbal instruction appropriately and immediately apply it to the second driving session. This result is also related to the results of the test-discontinuation items. Comparing the test-discontinuation items of the first and second driving sessions, especially the non-stop-related errors (Violation of temporary stop) were improved. We think that patients with higher MMSE scores were able to understand the verbal instructions given by the driving school instructor and immediately apply them to the second driving session, even if they missed the stop line, etc., during the first driving session. Based on previous studies, MMSE scores for patients who returned to driving after cerebrovascular disease were 26.0 ± 5.3 points in the study by Jee et al.[37] and 29.0 ± 2.0 points in the study by Perrier et al.[38] The MMSE score of patients who passed the second driving session in this study was 28.2 ± 1.7 points, which is close to the score reported in previous studies. In actual clinical situations, we believe that patients with MMSE scores in the high 20 s can be expected to benefit from rehabilitation. Moreover, the results for age (young) and sex (male), which were listed as predictors, as well as MMSE scores, were consistent with those reported in a previous study.[37] This suggests that young people and male can benefit from driving rehabilitation.

Next, driving rehabilitation consisted of two driving sessions and verbal instruction from the driving school instructor between the first and second driving sessions. Driving rehabilitation resulted in improved actual vehicle driving performance. Additionally, the number of participants who passed the test increased from two in the first session to 11 in the second session. We think that this result is based on two principles. The first is based on the principle of experience-dependent plasticity, and since the principles of experience-dependent plasticity include “Use It and Improve It,” we think that this also resulted in improved driving ability by driving a real car.[39] The second is based on the principle of motor learning, where more positive learning occurs when a skill is trained in situations similar to those in which the skill is performed.[40] Furthermore, in addition to the two driving sessions, we think that the verbal instruction from the driving school instructor between the first and second driving sessions was also effective. This allowed us to provide immediate feedback on the results of the first driving sessions and to make the participants aware of driving problems. Previous studies have provided insufficient evidence of rehabilitation for improving driving ability after cerebrovascular disease.[30] In contrast, this study can aid in establishing an evidence-based driving rehabilitation intervention for patients with cerebrovascular disease to support their resumption of driving.

Regarding the results of the test-discontinuation items evaluated in this study, which were classified into operation-related errors, non-stop-related errors, and other errors, showed that there was a decrease from the first to the second driving sessions, especially in the category of non-stop-related errors (Violation of temporary stop). Since stop-related errors can be prevented by the driver paying attention to signs, etc., it is thought that the feedback from the driving school instructor was reflected in the driving performance in the second driving session, leading to an improvement in performance. Conversely, we did not observe much improvement in operation-related errors. Since correcting driving operation errors requires the acquisition of important skills, such as steering wheel operation, it is likely that greater improvement in performance was not observed in this short period. Based on these results, future studies should analyze long-term progress to determine whether repeated training changes errors related to driving maneuvers over time. It is also important to verify whether these improvements can be sustained in the long run, even though this study improved compliance with traffic laws; for example, the temporary stop was violated less frequently.

4.1. Limitations

There are several limitations to this study. The first is the lack of information on the region of cerebrovascular disease, medication status, and psychiatric symptoms that may affect driving ability. Second, there is no control group in this study. Another limitation is that the actual vehicle driving was conducted twice on the same day due to issues such as participants' mobility. Therefore, although driving rehabilitation improved the actual vehicle driving performance, we cannot rule out the possibility that this is simply an effect of repetition. Future research should take these limitations into account and address them using randomized controlled trials, as well as examining the long-term effects of driving rehabilitation.

5. Conclusions

Herein, we investigated the relationship between neuropsychological tests and driving skills in patients with cerebrovascular disease and verified the effectiveness of driving rehabilitation at a driving school.

The results showed a relationship between MMSE scores and driving skill, indicating that MMSE scores are an important predictor of actual vehicle driving performance.

Driving rehabilitation at the driving school was found to have some positive effects, such as an increase in the pass rate for actual vehicle driving. However, it is necessary to consider the possibility that this effect could be due to the repetition of two driving sessions conducted on the same day.

This study can aid in establishing evidence-based driving rehabilitation interventions in patients with cerebrovascular disease to support their resumption of driving, which is critical to health, well-being, social interconnectedness, productivity, and quality of life.

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Data availability statement

The data used for this study, though not available in a public repository, will be made available to other researchers upon reasonable request.

Declaration

The authors report that there are no competing interests to declare.

Supplementary materials

Supplementary materials for this article can be found at http://www.sgecm.org.tw/ijge/journal/view.asp?id=28.

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